Transport Canada

Transportation Development Centre

Final Report

Comparative Technology Assessment Montreal — Mirabel — Ottawa High Speed Ground Transport

TP5457E

Centre/
1985
Transport Canada

Canatrans Consultants Ltd.

with Transrapid International

December 1984

Canatrans Project No. 37229

TP 5457E

COMPARATIVE TECHNOLOGY ASSESSMENT: MONTREAL - MIRABEL - OTTAWA HIGH SPEED GROUND TRANSPORT

Final Report

Chapters 1 to 9

Bernard-André Genest, Project Manager
Peter Jurgen Gaede, Marc Girardin, Marc Grégoire, Charles Schwier

This research was conducted under Supply and Services Canada Contract No. OSD82-00061, on behalf of the Advanced Technology Division, Transportation Development Centre, Transport Canada

Canatrans Consultants Ltd., Montreal (Quebec) Canada
with
Transrapid International, München (Federal Republic of Germany)

December 1984

This report resulted from research conducted through Canatrans Consultants Ltd. with Transrapid International. The report represents the views of the authors and does not necessarily have the endorsement of the performing organizations or that of the sponsoring agency.

REPORT DOCUMENTATION FORM

1 Transport Canada Report No
TP 5457E

2. TDC Project No
4609

3 Recipient's Catalogue No

4. Title and Subtitle
Comparative Technology Assessment:
Montreal - Mirabel - Ottawa
High Speed Ground Transport

5 Report Date
December 1984

6 Performing Organization Report No
37229

7 Author(s)
Bernard-André Genest, Peter Jurgen Gaede,
Marc Girardin, Marc Grégoire, Charles Schwier

8 Transport Canada File No
D1465-356-2

9 Performing Organization Name and Address
Canatrans Consultants Ltd.
1130 West, Sherbrooke Street
Montreal, Quebec, Canada H3A 2R5

10 DSS File No
10SD.T8200-2-2503

11 DSS or Transport Canada Contract No
0SD82-00061

12 Sponsoring Agency Name and Address
Transportation Development Centre (TDC)
Transport Canada
1000 West, Sherbrooke Street, suite 2421
Montreal, Quebec, Canada H3A 2R3

13 Type of Report and Period Covered
Final Report

14 Sponsoring Agency Code

15 Supplementary Notes
Report comprises two volumes: 1. Chapters 1 to 9
2. Technical Appendices

16 TDC Project Officer
Maurice Audette

17 Abstract

This report presents a comparative assessment of two technologies for high speed ground transport (HSGT): an electrified rail system using conventional wheel-on-rail technology with a maximum operating speed of 200 km/h, and an advanced system using magnetic attraction for vehicle support, guidance, and propulsion, with a maximum operating speed of 400 km/h.

The comparison is based on a given hypothetical application: service between Montreal and Ottawa, a distance of some 200 km, through Mirabel International Airport. Based on their technical characteristics and performance, a conceptual system design was developed for each technology, against common service specifications formulated to reflect the requirements of that application.

Detailed capital and operating cost estimates are presented. The estimated ticket cost is used as a basis for a comparative financial analysis; the sensitivity of that cost to the relevant economic parameters is explored. The report also contains an evaluation of the differences in impacts between the two technologies with emphasis on the environmental insertion of guideways for HSGT systems.

18 Key Words
High Speed Ground Transport, High Speed Rail, Maglev, Intercity Passenger Transport, Montreal, Ottawa, Financial Analysis, Impact Evaluation, Technology Assessment.

19 Distribution Statement
Limited number of copies available from TDC

20 Security Classification (of this report)
unclassified

21. Security Classification (of this page)
unclassified

22. No. of Pages
vol.1 352
vol.2 294

23. Price

FORMULE DE DOCUMENTATION POUR RAPPORT

1 Nº du rapport Transports Canada TP5457E	2 Nº de l'étude — CDT 4609	3 Nº de catalogue du destinataire

4 Titre et sous-titre
Comparative Technology Assessment:
Montreal - Mirabel - Ottawa
High Speed Ground Transport

5 Date du rapport
Décembre 1984

6 Nº du rapport de l'organisme exécutant
37229

7 Auteur(s)
Bernard-André Genest, Peter Jurgen Gaede,
Marc Girardin, Marc Grégoire, Charles Schwier

8 Nº de dossier Transports Canada
D1465-356-2

9 Nom et adresse de l'organisme exécutant
Canatrans Consultants Ltée
1130 ouest, rue Sherbrooke
Montréal, Québec, Canada H3A 2R5

10 Nº de dossier — ASC
10SD.T8200-2-2503

11 Nº de contrat — ASC ou Transports Canada
0SD82-00061

12 Nom et adresse de l'organisme parrain
Centre de développement des transports (CDT)
Transports Canada
1000 ouest, rue Sherbrooke, suite 2421
Montréal, Québec, Canada H3A 2R3

13 Genre de rapport et période visée
Rapport final

14 Code de l'organisme parrain

15 Remarques additionnelles
Rapport en deux volumes: 1. Chapitres 1 à 9
2. Annexes techniques
Rapport sommaire disponible en français

16 Agent de projet — CDT
Maurice Audette

17 Résumé

Ce rapport présente une évaluation comparative de deux technologies de transport terrestre guidé à grande vitesse: un système ferroviaire électrifié utilisant la technologie fer-sur-fer conventionnelle et doté d'une vitesse d'exploitation maximale de 200 km/h d'une part; et un système à technologie avancée utilisant des principes d'attraction magnétique pour la sustentation, le guidage et la propulsion du véhicule, d'autre part, ce dernier étant capable d'une vitesse d'exploitation maximale de 400 km/h.

La comparaison est basée sur une application hypothétique: un service grande vitesse entre Montréal et Ottawa, une distance de 200 km environ, via l'aéroport international de Mirabel. A partir de leurs données techniques et de performance, on a effectué pour chaque technologie la conception schématique d'un système complet à des normes de service communes, formulées pour répondre aux exigences de la clientèle envisagée.

Des estimations détaillées des coûts de mise en oeuvre et d'exploitation sont présentées dans le rapport, de même qu'une analyse financière comparative basée sur une évaluation du coût du titre de transport pour chaque système. On analyse la sensibilité de ce coût à des variations de la valeur des principaux paramètres économiques pertinents. Le rapport comprend aussi une évaluation des deux technologies quant aux différences dans leurs impacts; on y met l'accent sur les difficultés d'insertion dans le milieu des couloirs de circulation des systèmes de transport terrestre grande vitesse.

18 Mots-clés
Transport terrestre à grande vitesse, Transport ferroviaire, sustentation magnétique, Transport interurbain, Montréal, Ottawa, Evaluation d'impacts, Comparaison technologique.

19 Diffusion
Le CDT dispose d'un nombre limité d'exemplaires.

20 Classification de sécurité (de ce rapport) aucune	21 Classification de sécurité (de cette page) aucune	22 Nombre de pages Vol. 1 352 Vol. 2 294	23 Prix

TABLE OF CONTENTS

Page

1. CONTEXTUAL DATA AND TRAVEL DEMAND 1
- 1.1 Existing Transportation Networks 5
- 1.1.1 Road Network 6
- 1.1.2 Rail Network 6
- 1.1.3 Airline Distances and Flight Paths 8
- 1.2 Transportation Services 8
- 1.2.1 Intercity Bus Transportation 9
- 1.2.2 Airport Bus Services 9
- 1.2.3 Railway Passenger Services 9
- 1.2.4 Air Transport Services 10
- 1.3 Travel Demand 10
- 1.3.1 Intercity Demand 11
- 1.3.2 Airport-Related Travel 11
- 1.4 HSGT Traffic Estimates 16
- 1.4.1 Intercity Traffic: Forecasting Approach 19
- 1.4.2 Intercity Traffic: Forecasting Principles 20
- 1.4.3 Intercity Traffic: Base Forecasts 26
- 1.4.4 Airport-Related Traffic 28
- 1.4.5 Through Traffic 31
- 1.4.6 Induced Traffic 36
- 1.4.7 Commuter Traffic 38
- 1.4.8 Total Traffic 38

2. TECHNOLOGY DEFINITION 45
- 2.1 Key Parameteres of the Maglev Technology 46
- 2.2 Selection of a Rail Technology 54
- 2.3 Key Parameters of the Rail Technology 57

3. PERFORMANCE SPECIFICATION 61
- 3.1 Identification of the Target Market 62
- 3.2 Functional Requirements of Intercity Traffic 65
- 3.3 Performance Specification 67
- 3.3.1 Geographic Coverage 67
- 3.3.2 Level of Service 68
- 3.3.3 Safety 68
- 3.3.4 Ride Comfort 70

4. ROUTE SELECTION 73
- 4.1 Principles for Route Selection 74
- 4.2 Constraints to Route Selection 75
- 4.2.1 Land Use Constraints 75
- 4.2.2 Location of the Montreal Terminal 76
- 4.2.3 Location of the Mirabel Station 76
- 4.2.4 Technical Constraints for Maglev 78
- 4.2.5 Technical Constraints for Rail 79

TABLE OF CONTENTS (Cont'd.)

Page

4.3 Selection of an Alignment for Maglev 80
4.3.1 Montreal Terminal Location 80
4.3.2 Access/Egrees to/from Windsor Station 81
4.3.3 Location of a Suburban Station 82
4.3.4 Route through Laval 83
4.3.5 Station Location and Routing around Mirabel 84
4.3.6 Routing between Mirabel and Ottawa 84
4.4 Description of the Maglev Route 85
4.5 Selection of an Alignment for Rail 88
4.5.1 Montreal Terminal Location 88
4.5.2 Acces/Egrees to/from Central Stations 88
4.5.3 Location of a Suburban Station 89
4.5.4 Station location and Routing around Mirabel 89
4.6 Description of the Rail Route 90
References

5. RAIL SYSTEM DEFINITION AND COSTS 95
5.1 Basic Assumptions for System Definition 96
5.1.1 Geographic Coverage 96
5.1.2 Routing 96
5.1.3 Time Coverage 97
5.1.4 Frequency of Service 97
5.1.5 Capacity 97
5.1.6 Safety 97
5.2 Methodology for System Definition and Cost Estimation 98
5.2.1 Sub-system and Geographic Disaggregation 98
5.2.2 Design Conditions 99
5.2.3 Principles for Cost Estimation 99
5.2.4 Cost Estimation Methodology 100
5.3 Capacity Definition 101
5.4 Vehicles 104
5.5 Infrastructure 107
5.5.1 Track Layout 107
5.5.2 Right-of-Way Requirements, Acquisition, and Rental 108
5.5.3 Track: Rail, Ties, Fasteners 112
5.5.4 Track Structure Design 114
5.5.5 Track Construction 117
5.5.6 Turnouts 118
5.5.7 Capital Costs for Infrastructure 120
5.6 Structures 122
5.6.1 Typical Grade Separations 122
5.6.2 Special Structures 126
5.6.3 Bridges and Culverts 128
5.6.4 Capital Costs for Structures 131
5.7 Stations 135

TABLE OF CONTENTS (Cont'd.)

Page

5.8 Power and Control Equipment 138
5.8.1 Power Supply 138
5.8.2 Power Distribution 139
5.8.3 Command and Control 142
5.8.4 Communications 145
5.8.5 Auxiliary Equipment 146
5.8.6 Maintenance Equipment 146
5.9 Operating Procedures, Personnel and Costs 147
5.9.1 Overview of System Operating Policies 147
5.9.2 On-Board Personnel 149
5.9.3 Station Personnel 150
5.9.4 Reservation Personnel 152
5.9. System Operation Personnel 154
5.9.6 Rail Operating Cost 156
5.10 Maintenance Procedures, Personnel, and Costs 158
5.10.1 Rolling Stock 158
5.10.2 Track and Structures 159
5.10.3 Power System 161
5.10.4 Signaling and Communications 162
5.10.5 Stations, Buildings and Facilities 163
5.10.6 Total Maintenance Costs 163
5.11 Power Consumptions Costs 165
References 167

6. MAGLEV SYSTEM DEFINITION AND COSTS 169
6.1 Basic Assumptions Underlying System Definition 170
6.1.1 Geographic Coverage 170
6.1.2 Routing 171
6.1.3 Time Coverage 171
6.1.4 Frequency of Service 171
6.1.5 Capacity Strategy 171
6.1.6 Safety 171
6.2 Methodology and for System Definition and Costing 172
6.2.1 Sub-system Geographic Disaggregation 172
6.2.2 Design Conditions 172
6.2.3 Principles for Cost Estimation 173
6.2.4 Cost Estimation Methodology 174
6.3 Capacity Definition 175
6.4 Vehicles 178
6.5 Infrastructure 184
6.5.1 Guideway Layout 184
6.5.2 Right-of-way Requirements, Acquisition, and Rental 184
6.5.3 Building Relocation 189
6.5.4 Site Preparation 190
6.5.5 Infrastructure Costs 192

TABLE OF CONTENTS (Cont'd.)

Page

6.6 Guideway Design, Structure and Costs 193
6.6.1 Structural Requirements for the Guideway 193
6.6.2 Description of Structural Elements 193
6.6.3 Guideway Configuration for the Application 195
6.6.4 Beams: Design and Unit Cost 199
6.6.5 Bearings: Design and Unit Cost 200
6.6.6 Piers. Design and Unit Costs 202
6.6.7 Foundation Elements: Designs and Unit Costs 204
6.6.8 Total Cost of the Basic Structure 208
6.6.9 Additional Costs for Special Structures 211
6.6.10 Total Construction Costs 214
6.7 Guideway-Mounted Equipments 217
6.7.1 Equipment Installation Process 217
6.7.2 Guidance Rails 220
6.7.3 Long Stator 220
6.7.4 Turnouts 222
6.7.5 Information System 224
6.7.6 Guideway Equipment Costs 224
6.8 Stations 226
6.9 Power Supply Equipment 229
6.10 Auxiliary Equipment 235
6.10.1 Communications 235
6.10.2 Maintenance Building 236
6.10.3 Maintenance Equipment 236
6.11 Operating Procedures, Personnel, and Costs 237
6.11.1 Overview of System Operating Policies 237
6.11.2 On-Board Personnel 238
6.11.3 Station Personnel 240
6.11.4 Reservation Personnel 243
6.11.5 System Operation Personnel 243
6.11.6 Maglev Operating Costs 246
6.12 Maintenance Costs 248
6.13 Power Consumption Costs 250

7. FINANCIAL ANALYSIS AND SYSTEM OPTIMIZATION 253
7.1 Analysis of Capital Costs 256
7.1.1 Construction and Procurement Costs 256
7.1.2 Legal, Design, and Engineering Costs 257
7.1.3 Comparison of Capital Costs 260
7.1.4 Plant Expansion and Renewal Costs 262
7.1.5 Time-Staging of Investments 264
7.2 Recurring Costs 264
7.2.1 Operating Salaries and Materials 264
7.2.2 Maintenance Labour and Supplies 265
7.2.3 Supply and Energy Consumption 270

TABLE OF CONTENTS (Cont'd.)

Page

7.2.4 Land and Building Leasing 270
7.2.5 Administration 270
7.2.6 Total Recurring Costs 270
7.3 Objectives of the Financial Analysis 273
7.4 Financial Analysis Methodology 275
7.4.1 Output Units 276
7.4.2 Financial Parameters 277
7.5 Financial Analysis Results 280
7.5.1 Rail System 280
7.5.2 Maglev System 282
7.5.3 Comparison between Rail and Maglev in the Base Case 282
7.6 Sensitivity Analysis 287
7.6.1 Traffic Volume 287
7.6.2 Inflation and Cost Escalation 288
7.6.3 Residual Value and Project Life 290
7.6.4 Tax and Corporate Structure 292
7.6.5 Financing Costs and Methods 293
7.6.6 Changes in Costs 294
7.6.7 Conclusions 296
7.7 System Optimization 299
7.7.1 Single Track Rail System 299
7.7.2 Single Guideway Maglev System 301

8. IMPACT EVALUATION 305
8.1 Evaluation Methodology 307
8.2 Technical Risk Evaluation 308
8.2.1 Technical imponderables 308
8.2.2 Winter Operation 310
8.3 Energy Impacts 312
8.3.1 Energy Requirements 312
8.3.2 Consumption of Direct Energy 313
8.3.3 Annual Consumption of Indirect Energy 313
8.3.4 One-Time Consumption of Indirect Energy 316
8.4 Employment Impacts 319
8.4.1 Permanent Employment for System Operation 319
8.4.2 Temporary Employment for System Implementation 320
8.5 Aesthetic and Environmental Impacts 325
8.5.1 Noise 325
8.5.2 Visual Intrusion 327
8.5.3 Environemental Insertion of HSGT Rights-of-way 328

9. MAJOR RESULTS AND FINDINGS 333

LIST OF FIGURES

Page

1-1 Montreal, Mirabel, Ottawa. Key Topographical Features 7
1-2 Montreal, Mirabel, Ottawa. Rail Network Configuration 7
1-3 Forecasts of Total Future Traffic for HSGT 39

2-1 Maglev Vehicle. General View and Main Dimensions 47
2-2 Cross-Section of the Maglev Vehicle on the Guideway 49
2-3 Maglev Guideway Clearances for Elevated Construction 50
2-4 Maglev Guideway in Cut or at Grade 51
2-5 Maglev Guideway in a Tunnel 51
2-6 LRC Coach. General View 59

4-1 Location and Configuration of Mirabel Station 77
4-2 Proposed Maglev Route 87
4-3 Proposed Rail Route 91

5-1 Traffic Growth and Capacity Adjustment for Rail 102
5-2 Train Traffic Pattern for Rail 103
5-3 Summary Track Schematic for Rail 109
5-4 Track Structure Designs 115
5-5 Typical Street-under-Rail Grade Separation 123
5-6 Typical Road-over-Rail Grade Separation 125

6-1 Traffic Growth and Capacity Adjustment for Maglev 176
6-2 Train Traffic Pattern for Maglev 177
6-3 Maglev Vehicle. General View and Main Dimensions 179
6-4 Levitation, Guidance, and Propulsion Equipments on the vehicle 181
6-5 Summary Guideway Schematic for Maglev 185
6-6 At-Grade Guideway on Footings 194
6-7 Maglev Guideway Configuration 196
6-8 A-Shaped Pier on Piles for an Elevated Guideway 198
6-9 Fabrication Process for a Guideway Beam 201
6-10 Cost Behavior of Guideway Foundation Elements 206
6-11 Rail Laying Train 216
6-12 Cable Laying Vehicle 218
6-13 Longstator Packages Mounted below the Guideway 221
6-14 Maglev Turnout in Branching Position 223
6-15 Power Supply Concept 231
6-16 Energy Supply System for Longstator Operation 234

7-1 Scheduling of Capital Cast Expenditures 263
7-2 Variation of Direct Operating Costs with Time 265
7-3 Variation of Maintenance Costs with Time 266
7-4 Variation of Receiving Costs with Time 271
7-5 Variation of Ticket Cost with Changes in Costs 297

LIST OF TABLES

Page

1-1 Intercity Travel Demand and Forecasts (all modes) 13
1-2 Base Data and Forecasts for Intercity Travel Demand 15
1-3 Base Data and Forecasts for Airport-Related Travel Demand 17
1-4 Observed Modal Split for Intercity Travel 21
1-5 Modal Share Estimates for Intercity Travel 23
1-6 Estimates of Future Base Intercity Traffic for HSCT 25
1-7 Intercity Traffic Forecast for a High-Speed Rail Service 27
1-8 Forecasts of Base Intercity Traffic for Rail 29
1-9 Forecasts of Base Intercity Traffic for Maglev 30
1-10 Modal Split for Airport Access to Mirabel 32
1-11 Forecasts of Base Airport - Related Traffic for Rail 34
1-12 Forecasts of Base Airport - Related Traffic for Maglev 35
1-13 CIGGT Scale Factors for Induced Demand 37
1-14 Forecasts of Total Traffic for Rail 40
1-15 Forecasts of Total Traffic for Maglev 41

2-1 Technical Parameters of the Maglev Technology 53
2-2 Technical Parameters of the Rail Technology 60

3-1 Performance Specification 69

5-1 Right-of-Way Requirements for the Rail Route 110
5-2 Capital Costs for Rail Infrastructure 121
5-3 Treatment of Cross Roads for Rail System Definition 124
5-4 Requirements for Typical Grade Separation Structures 127
5-5 Unit Costs for Grade Separation Structures 133
5-6 Capital Costs for Rail Structures 134
5-7 Capital Costs for Rail Stations 137
5-8 Capital Costs for Rail Power Supply Equipment 141
5-9 Summary of Command and Control Equipment Requirements 143
5-10 Capital Costs for Rail Signalling Equipment 144
5-11 Salary Costs for Rail Personnel 148
5-12 Station Operation Personnel for Rail 153
5-13 System Operation Personnel for Rail 155
5-14 Breakdown of 1991 Operating Costs for Rail 157
5-15 Maintenance Costs for Rail (1991) 164

6-1 Breakdown of the Maglev Vehicle Cost 183
6-2 Right-of-way Requirement for the Maglev Route 187
6-3 Capital Costs for Maglev Infrastructure 191
6-4 Unit Costs for Guideway Piers 203
6-5 Unit Costs for Guideway Foundation Elements 205
6-6 Unit Kilometric Costs for Guideway Foundations and Piers 207
6-7 Unit Kilometric Costs for Guideway Construction 209
6-8 Basic Guideway Structure Costs 210
6-9 Cost Surplus for River Crossings 213
6-10 Summary of Maglev Guideway Structure Costs 215

LIST OF TABLES (Cont'd.)

		Page
6-11	Capital Costs for Maglev Guideway Equipments	225
6-12	Capital Costs for Maglev Stations	227
6-13	Capital Costs for Maglev Power Supply	233
6-14	Salary Costs for Maglev Personnel	239
6-15	Station Operation Personnel for Maglev	241
6-16	System Operation Personnel for Maglev	245
6-17	Breakdown of 1991 Operating Costs for Maglev	247
6-18	Maintenance Costs for Maglev	249
7-1	Summary Direct Capital Costs for Rail	254
7-2	Summary Direct Capital Costs for Maglev	255
7-3	Comparative Capital Costs for Rail and Maglev	259
7-4	Comparative Life Expectancy of System Components	261
7-5	Comparative Operating Costs in 1991	268
7-6	Comparative Maintenance Costs in 1991	269
7-7	Comparative Annual Costs in 1991	272
7-8	Base Case Cash Flow Summary for Rail	281
7-9	Base Case Cash Flow Summary for Maglev	283
7-10	Comparative Ticket Costs, Base Case	285
7-11	Revenue Contribution Requirement by Cost Component	286
7-12	Sensitivity of Ticket Cost to Traffic Volume	289
7-13	Sensitivity of Ticket Cost to Operating Cost Escalation	291
7-14	Sensitivity of Ticket Cost to Financing Rate	295
7-15	Comparative Capital Costs for Single Track/Guideway Systems	303
8-1	Annual Energy Consumption Estimates	315
8-2	Base Data for Indirect Energy Consumption	317
8-3	Indirect Energy for Manufacturing and Construction	318
8-4	Comparative Evaluation of Permanent Employment Creation	321
8-5	Evaluation of Temporary Employment Creation by Rail	323
8-6	Evaluation of Temporary Employment Creation by Maglev	324

INTRODUCTION

This study is concerned with high speed ground transportation systems (HSGT) used for intercity passenger transport.

The primary objective of the study is to perform a comparative assessment of two different HSGT technologies: a rail system designed along conventional principles and a magnetic levitation system. This comparative assessment must identify, evaluate, and analyze the major differences between the two technologies, accounting for their levels of service, capital costs, annual costs, and impacts.

The secondary objective of the study is to research and document comprehensive, state-of-the-art, technical and cost data for both systems, and to present that data in order to facilitate its use by transportation planners and decision-makers.

Fulfillment of these objectives required a clear understanding of the essential differences between magnetic levitation and conventional railway technologies. As this study is not a planning study, no attempt was made to formulate synthetic judgements as to (1) whether one or both systems is desirable, justified, or justifiable and/or (2) which system is superior or preferable overall.

For the comparitive assessment to maintain the correct focus and emphasis, all non-essential elements were given only the minimum reasonable attention, given the scope of the study: the objective of the study was not to generate an exhaustive enumeration of all system components, nor was it to prepare a comprehensive estimate of all capital and annual costs.

For realism in the the comparison, the study took into consideration the contextual characteristics of a specific application: its geography, topograpny, service requirements, etc. The Terms of Reference specified, as the application to be analyzed, a high speed service between Ottawa and Montreal with (at least) one intermediate station at Mirabel International Airport.

Although it may limit the generalization of the conclusions, the use of a given corridor as a test-bed presents significant advantages for the study. In particular, this approach facilitates the development of a well-adapted system design that takes into consideration physical as well as institutional and other constraints. It thus provides a good measure of a technology's flexibility and responsiveness to given conditions.

The approach used in the study made maximum use of available data and complementary data was obtained from original sources whenever possible. This provided a more credible basis for analysis and made it easier to organize and to document the results of the study for comparison with those of other studies.

The method used in the comparative assessment consisted of the following steps:

- definition of a technology reference;
- traffic forecasts;
- formulation of common service specifications;
- preliminary system design, adapted to the application;
- estimation of capital and operating costs;
- impact evaluation;
- summary comparative assessment.

The purpose of defining a reference was to fix, at the outset, the most significant technical parameters that characterize each technology; in other words, to identify precisely what was being compared: dimensions and clearances, speed, acceleration, deceleration, curveability, gradeability, weight, and power requirements, etc. These parameters are the basis in establishing system requirements, configuration, and performance. They are discussed in Chapter 2.

Based on the assumed performance, traffic forecasts were prepared for each HSGT technology. This was done by market segment: intercity, airport access, etc. The data was not collected. Instead, new forecasts were prepared by modifying available forecasts, to reflect the performance of each technology and the observed elasticity of Montreal-Ottawa travel demand to travel time. Traffic forecasts are presented in Chapter 1.

Common service specifications were developed to be used as a basis for defining a system for each technology. Common service specifications were used to eliminate from the comparison any advantage or preference factor that was not technology-related (Chapter 3).

A complete system was then defined (conceptually) for each technology; it met (or exceeded) the service specifications. This definition covered all system components: general configuration, routing (Chapter 4), fleet size, track or guideway layout, infrastructure, structures and bridges, power and control equipment, stations, facilities and auxiliary equipment, as well as operation and maintenance procedures and personnel. The system definition and cost estimation are presented in Chapter 2 for Rail and Chapter 6 for Maglev. Since they resulted form common specifications, both system designs were comparable or identical in several key service parameters, such as frequency and number of stations.

An estimate of capital and annual costs was developed for each system, using the same assumptions and principles. A financial analysis was performed on each system, to determine the revenue requirements necessary for profitable and solvent operation. The resulting estimated ticket cost was analyzed for its sensitivity to variations in key economic parameters: general and component cost escalation, financial parameters, traffic volume, and changes in capital or annual costs. This is explained in Chapter 7.

The same analysis was performed for "optimized" systems where double track or guideway was provided only inasmuch as necessary for the requirements of the Montreal-Mirabel-Ottawa traffic alone.

Finally, major differences in impacts between the two systems were identified. Impacts considered included technical spin-offs, energy consumption, employment creation and socio-economic, aesthetic, and environmental factors.Impacts are discussed in Chapter 8.

1. CONTEXTUAL DATA AND TRAVEL DEMAND

This chapter consists of four sections. The first one describes the major transportation networks linking Montreal, Mirabel and Ottawa. The second section describes the transportation services presently offered in this corridor. The third deals with observations of present and future travel demand for existing modes, while the fourth provides traffic estimates for high speed ground transportation services.

The ridership estimates presented in this chapter were based on available travel demand data and traffic forecasts. No new data was generated in the present study, which is, in essence, a comparative assessment of two technologies for high speed ground transport (HSGT).

The available traffic forecasts were adjusted to the characteristics envisioned for the systems evaluated in this study, including their proposed alignments, which are described in Chapter 4. Modifications of these characteristics or alignments, for one technology or both could change the conclusions of the present chapter, as explained in Chapter 7.

Nevertheless, the traffic estimates presented herein constitute a legitimate and reasonable basis for conducting, in a realistic manner, the comparative technology assessment that is the objective of the present study.

1.1 Existing Transportation Networks

The island of Montreal is located at the junction of the Ottawa and Saint Lawrence Rivers. Ottawa is located 180 km upstream of Montreal on the Ottawa River. As it is the federal capital and Montreal the metropolis nearest to it, there are numerous road, rail and air transportation routes and services linking these two cities.

The key topographical features are shown in Figure 1-1. The terrain between Montreal and Ottawa is practically flat.

1.1.1 Road Network

Automobile travel between Montreal and Ottawa is easy. Leaving the center of Montreal, one can drive to a point almost at the center of Ottawa by a succession of four-lane, access-controlled, divided expressways, which connect one another: Autoroutes 20, Décarie, and 40 in Quebec and Expressway 417 in Ontario. The distance between the two city centers is approximately 195 km along this route and the travel time normally around 2 hours. Alternatively, after leaving the Province of Quebec on Autoroute 40, one can reach Ottawa using Ontario Provincial Highway 17, which is neither divided nor access-controlled. The distance is 181 km, but the travel time is somewhat longer.

Mirabel can be reached from the center of Montreal by road using a succession of expressways: Autoroutes 20, Décarie, 40 (Boulevard Métropolitain), and 15 (Autoroute des Laurentides); the distance is 50 km. Mirabel can be reached from Ottawa by road in two ways: either using Expressway 417 from Ottawa and crossing the Ottawa River at Hawkesbury and then following Quebec Highways 148 and 158; or crossing the Ottawa River to Hull when leaving Ottawa, and then following Quebec Highways 148 and 158. The distance is 150 km in the former case and 145 km in the latter; travel is more difficult.

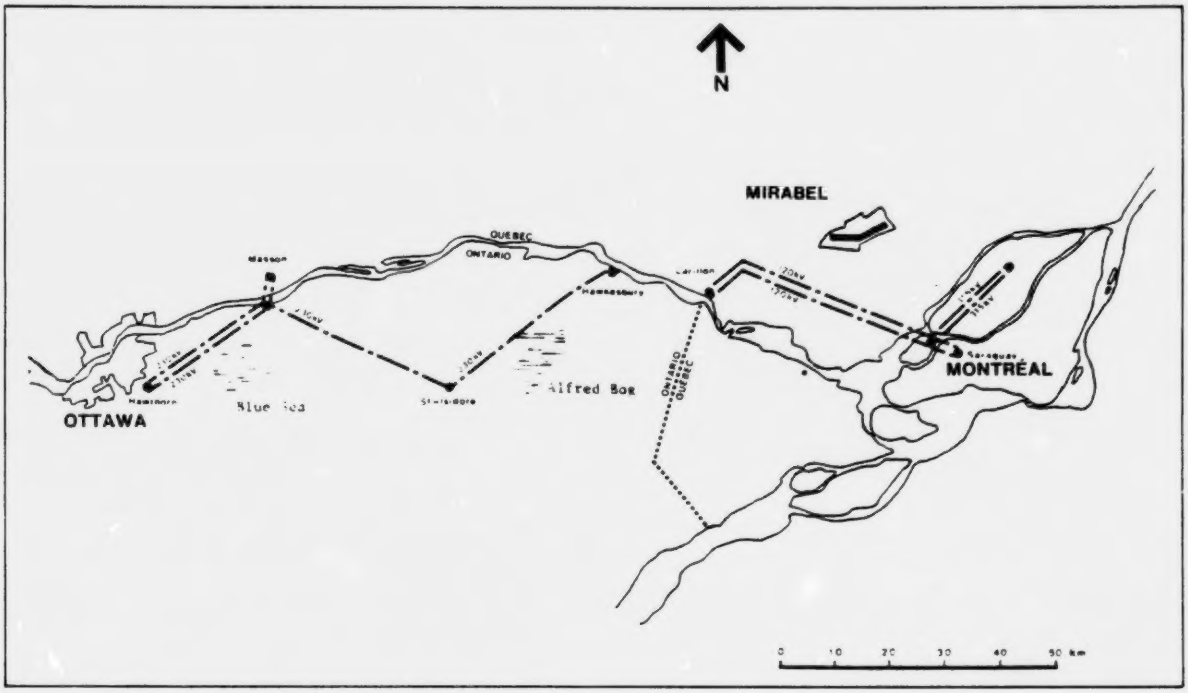

N
MIRABEL
QUEBEC
ONTARIO
Masson
Hawkesbury
Carillon
120kV
230kV
Hawthorne
OTTAWA
Blue Sea
St-Isidore
Alfred Bog
ONTARIO
QUEBEC
MONTREAL
0
10
20
30
40
50 km

Figure 1-1 Montreal, Mirabel, Ottawa: Key Topographical Features and High Voltage Power Lines

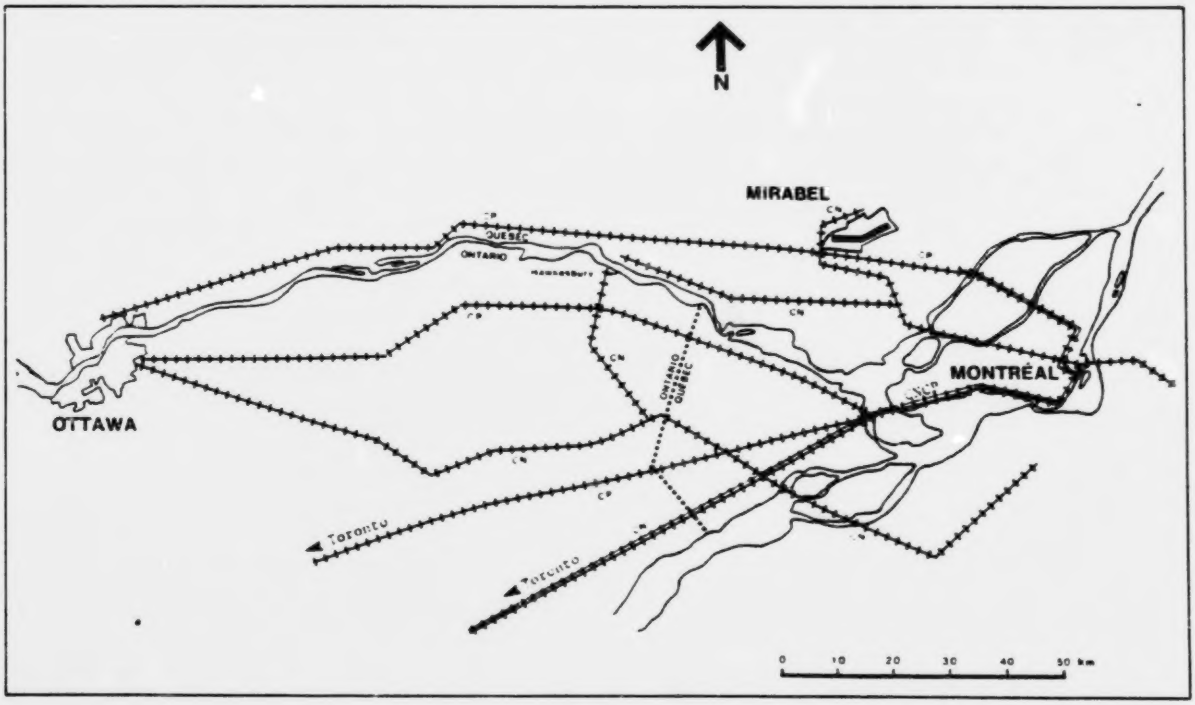

N
MIRABEL
CP
CN
QUEBEC
ONTARIO
Hawkesbury
OTTAWA
MONTREAL
Toronto
Toronto
0
10
20
30
40
50 km

Figure 1-2 Montreal, Mirabel, Ottawa: Rail Network Configuration

1.1.2 Rail Network

There are three possible railway connections between Montreal and Ottawa, two on the right shore of the Ottawa River and one on the left shore, they are shown schematically in Figure 1-2.

The only railway route on which services are now operated by VIA Rail uses Canadian National (CN) rights-of-way: after leaving Central Station in Montreal, the route successively follows CN Subdivisions Montreal, Kingston, Alexandria, and Ottawa. The distance along this route is 187 km.

The other route on the right shore is on a Canadian Pacific (CP) right-of-way: after leaving Montreal from Windsor Station, this route successively follows CP Subdivisions Westmount, Vaudreuil and M.&O., and CN Subdivision Ottawa. The distance along this route is 175 km.

A third route, on the left shore, is on a CP right-of-way: leaving Montreal from Windsor station, this route follows successively CP Subdivisions Westmount, Adirondack, Park Avenue, Lachute and Ellwood, and CN Subdivision Ottawa. The distance along this route is 213 km.

1.1.3 Airline Distances and Flight Paths

Airline distances are 151 km between Dorval and Ottawa, 133 km between Mirabel and Ottawa and 31 km between Dorval and Mirabel. Flight path distances are, respectively, 161, 145, and 31 km.

1.2 Transportation Services

This section gives information on passenger transportation services presently offered in the Montreal - Mirabel - Ottawa corridor by the different modes.

1.2.1 Intercity Bus Transportation

Intercity bus service between Montreal and Ottawa is provided by Voyageur Inc. There are a total of 22 trips in each direction daily during the week, 19 of which are express and 3 local. Nine of the express busses stop at Dorval. Travel time varies between 2h10 and 2h30 for express busses and between 4h05 to 4h15 for local busses. The fare is currently (mid-1983) $12.90 for a one-way trip and $15.95 for a same-day two- way trip.

1.2.2 Airport Bus Services

There are airport bus services between Mirabel, Dorval and downtown Montreal. Murray Hill operates a bus service between Dorval and downtown Montreal. Minimum and maximum headways are 20 and 30 minutes. The one-way fare is currently $5.00 and the service is offered between 5h00 and 24h00.

The transit commission of the Montreal Urban Community (C.T.C.U.M.) operated a recently-discontinued bus service between Dorval and Mirabel. Headway is 40 minutes and service is offered between 11h00 and 21h40. The fare is currently $9.00 for a one-way trip. The C.T.C.U.M. also operated a service between downtown Montreal and Mirabel. Headway is 50 minutes. Operating hours and fare were the same as the Dorval-Mirabel service. Private companies now operate airport services.

1.2.3 Railway Passenger Services

As at mid-1983, VIA Rail operated 6 daily trains in each direction between Montreal and Ottawa, 3 of which are by self-propelled rail diesel cars (RDC's). This service uses the CN line from Central Station and all trains stop at Dorval. Travel time varies between 1h55 and 2h10. Although the trains terminate at the Ottawa Station, VIA Rail offers a bus connection to Ottawa downtown and to Hull ($0.75 for a one-way trip). The "coach" fare is currently $15.00 for a one-way trip and $18.00 for a same-day two-way trip; the "club" fare is $23.00 one-way.

Train service between Montreal and Ottawa by the north shore via Lachute near Mirabel (CP line) was discontinued in 1981.

1.2.4 Air Transport Services

There are 5 airlines offering transportation between Montreal and Ottawa: Air Canada, CP Air, Nordair, Air Atonabee, and First Air. The first four carriers serve Dorval, whereas First Air serves Mirabel only.

There are 17 daily trips in each direction to/from Dorval and 3 daily trip in each direction to/from Mirabel. Travel time varies between 30 and 35 minutes both for Dorval and Mirabel. The fare is currently $72.00 (excluding tax) for a one-way trip and $144.00 for a two-way trip.

1.3 Travel Demand

The objective of this section is to present a summary of data and forecasts of the present and future travel demand for all modes, from which the ridership of any future high speed ground transport system (HSGT) would be drawn.

According to the terms of reference, the present study is to present no new data or forecasts on travel demand and/or expected ridership, as it must concentrate on technology assessment. As explained below, however, it has proven necessary to complement published data and forecasts in certain respects.

Demand for travel between Montreal, Mirabel, and Ottawa consists of two distinct and different market segments: intercity travel and airport-related travel. These two segments will be reviewed separately.

1.3.1 Intercity Travel

The general lack of comprehensive and recent data on intercity travel flows between Montreal and Ottawa prevents systematic comparisons between available forecasts.

The first detailed traveler survey was performed in 1969 and 1970 as part of the Intercity Passenger Transport Study (1)*. This survey, which covered only common carriers, provides no data for automobile travel, which is the dominant mode between Montreal and Ottawa.

Between 1973 and 1976, as part of the STOL Demonstration Project, another systematic traveler survey was conducted (7). This survey provided data on automobile travel between Montreal and Ottawa, which was obtained by administering questionnaires to motorists sampled at selected locations.

---

* Numbers in brackets refer to entries in the list of references at the end of the chapter.

Apart from these surveys, Origin-Destination data for air travel between Montreal and Ottawa is available from Statistics Canada up to 1980 (14). Rail travel data is also published, with some delay; data for 1982 was provided by VIA Rail. Finally, the bus traffic can be estimated from a 1979 survey conducted for Transport Canada (16).

Present intercity travel demand data has thus been compiled from different sources for the various modes. It appears in Table 1-1. The studies referred to above also provided forecasts of future travel demand by mode. These are shown in the shaded area of Table 1-1.

These forecasts were prepared at a time when there were few indices as to the emergence and severity of the 1982 economic crisis. As a result, if one compares these forecasts with actual data for the latest years for which observed data is available, predicted demand exceeds actual demand, sometimes significantly. For instance, travel demand in 1980 for all common carriers, as predicted by the STOL Study (6) is 1 340 000 trips; actual demand, as estimated from observed data, is 979 000 trips; if one considers all modes, predicted demand is 5 326 000 trips and actual demand would be, presuming a 71% market share for auto, 3 376 000 trips: an overprediction of 58% for a four-year horizon. These forecasts could not be used.

The approach adopted here was to use the last year for which comprehensive trip data was available: 1976. Based on that data, as well as on the latest ridership data for given modes, total travel demand for 1982 was estimated to be 3 489 500 person-trips (Table 1-2).

Table 1-1

Intercity Travel Demand and Forecasts (all modes),
(Montreal-Ottawa x1000 person-trips per year)[4]

Year	Intercity Passenger Transport Study, 1970 (1)				Passenger Transportation Montreal-Ottawa, 1976 (7)							STOL and SHORT Haul Air Transportation in Canada, 1978 (6)						Statistics Canada (14)	Data from VIA Rail	Voyageur Survey (15)
	Air	Rail	Bus	Total	Air	STOL	Rail	Bus	Sub-Total	Auto	Total	Air	Rail	Bus	Sub-Total	Auto	Total	Air		
1969	49	402	254	705														47		
1970	51	416	263	730														41		
1971																		68		
1972																		74		
1973					98	-	189	347	834	2 061	2 893							98		
1974					88	38	193	366	885	2 118	3 003							88		
1975	77	624	394	1 095	60	94	163	389	906	2 310	3 216							60		
1976					60	23	172	673	928	2 296	3 224							61		
1977																		60		
1978																		58	300	
1979																		54	342[2]	600[3]
1980	103	832	525	1 460								147	198	995	1 340	3 986	5 326	49	328	
1981												156	203	1 055	1 414	4 199	5 613		402	
1982												165	210	1 118	1 493	4 423	5 916		338	
1983												175	216	1 185	1 576	4 659	6 235			
1984												186	222	1 257	1 665	4 907	6 572			
1985	136	1 104	697	1 937								197	229	1 332	1 758	5 169	6 927			
1986												208	236	1 404	1 848	5 439	7 287			
1987												219	243	1 480	1 942	5 722	7 664			
1988												231	250	1 559	2 040	6 021	8 061			
1989												243	258	1 642	2 143	6 335	8 478			
1990	175	1 425	900	2 500								256	265	1 732	2 253	6 665	8 918			

Notes:
1. Voyageur strike.
2. 225 221 for 8 months: 12/8 (225 221) = 337 832.
3. 1 717/day for 5 days: 1 717 x 350 = 600 000.
4. Trips from Montreal to Ottawa and from Ottawa to Montreal. Henceforth, these will be referred to as "bi-directional" trips.
5. Numbers in shaded areas are demand forecasts; other numbers are observed, compiled, or estimated flows.

Future ridership by mode was then estimated, based on annual growth for each mode rates estimated recently by Transport Canada's Strategic Planning group, using various scenarios for future economic conditions (15). The intermediate scenario was adopted for the period 1982-2001. The results are shown in Table 1-2.

These published growth rates have two major advantages for this study. They are based on the latest economic developments. Also, they are based on the presumption of no major change in the relative attractiveness of the various modes other than those resulting indirectly from exogeneous economic factors.

When summed for all modes, the resulting forecasts provide a good indication of the "event-free" evolution of the Montreal-Ottawa intercity travel market, thus an approximation of total intercity travel demand. This total, then, will be used in the present study as the base travel demand, i.e. the potential market from which the two HSGT systems being compared will draw their intercity ridership.

The induced demand resulting from the attractiveness of these systems will be considered separately when forecasting their traffic (Section 1.4).

Table 1-2

Base Data and Forecasts for Intercity Travel Demand
(x1000 bi-directional person-trips per year between Montreal and Ottawa)

Year	Mode				Total
	Air	Rail	Bus	Auto	
1976 (1)	68,3	177,8	675,0	2302,2	3223,3
1982	49,0 (2)	338,0 (3)	600,0 (4)	2502,5 (5)	3489,5
1986 (6)	54,3	403,1	657,1	2708,8	3823,3
1991 (7)	63,8	497,5	729,1	2976,1	4266,6
2001 (7)	88,4	758,0	897,5	3592,4	5336,3

Notes:
(1) Observed (References 6, 7).
(2) Estimated (Reference 14).
(3) Estimated from Via Rail data.
(4) Estimated (Reference 16).
(5) Assuming an average annual growth rate of 1,4% from the latest data.
(6) Assuming an average annual growth rate between 1981 and 1986, as in Transport Canada's Strategic Planning Group report (Reference 4):
- 2,6% for air mode;
- 4,5% for rail mode;
- 2,3% for bus mode;
- 2,0% for auto mode.

(7) Assuming an average annual growth rate between 1986 and 2001, as in Transport Canada's Strategic Planning Group report for 1986-1991 (Ref. 4)
- 3,3% for air mode;
- 4,3% for rail mode;
- 2,1% for bus mode;
- 1,9% for auto mode.

1.3.2 Airport-Related Travel

As in the previous sub-section, the objective here is to estimate the total demand for airport-related travel to and from Mirabel. This constitutes the market potential from which the HSGT services would draw their airport-related traffic.

Primary sources of data for estimating airport-related demand for a future Rail or Maglev are reports by Transport Canada (11, 12, 13, 17, 18, 19). These reports contain data and forecasts on the number of air travelers originating and terminating at Mirabel Airport, as well as on the number of connecting passengers.

When estimating future demand, it was presumed that international flights (i.e. to all foreign countries except the U.S.A.) would be the only ones using Mirabel Airport during the periode considered in this study.

Surveys were conducted in 1972 and in 1977 on Mirabel originating-terminating (O.T.) passengers, their local origin or destination and their use of ground transport services. Their choice of an access/-egress mode to/from Mirabel Airport can be estimated from the results of these surveys (11, 17, 18). Connecting passengers are those that connect from one flight to another in Mirabel; the number of connecting passengers from/to Ottawa can be found in one of the references (11). These two groups will be considered separately.

To estimate the number of O.T. air travelers of interest (i.e. potentially attracted) to a HSGT service serving Mirabel, this market was segregated according to the local origin or destination of air travelers, the basis on which an air traveler could consider using the HSGT service for airport access.

Table 1-3

Base Data and Forecasts for Airport-Related Travel Demand at Mirabel

Year	Total number of International originating-terminating passengers(1)	Origin or Destination		
		Montreal Downtown (2)	West Island (3)	Ottawa (4)
1977	1 121,0	412,5	118,8	88,6
1980	1 054,2	388,0	111,8	83,3
1982	920,0	338,6	97,5	72,7
1986	1 120,0	412,2	118,7	88,5
1991	1 270,0	467,4	134,6	100,3
1996	1 380,0	507,8	146,3	109,0
2001	1 510,0	555,7	160,1	119,3

Notes: (1) From Reference 19.

(2) This market segment includes downtown, west of downtown and the South Shore and corresponds to Zones 3, 4 and 9 of the 1977 survey; it represents 36,8% of international air travelers (11, 17).

(3) This market segment includes Lachine, Dorval, and municipalities to the west of Dorval on the Island of Montreal. it corresponds to Zones 5 and 6 of the 1977 survey and represents 10,6% of the international air travelers (11, 17).

(4) This represents 7,9% of international air travelers (18).

Only travelers originating from the city centre or the South Shore were considered susceptible to be attracted to a downtown HSGT Station for airport access. Air travelers originating from (or destined to) the eastern and northern parts of Montreal Island or outside of it (except the South Shore) are presumed not willing to backtrack to the city cenre to take a HSGT service to go to Mirabel. As a result, 36,8% of Mirabel O.T. passengers could (but not necessarily would) be attracted to Rail or Maglev and constitute the first portion of its market potential.

Based on the same approach 10,6% of all originating-terminating travelers are from the West Island and could use Rail or Maglev if it had a convenient suburban station (11, 17).

The same approach was applied again, to O.T. air travelers from/to Ottawa, who represent 7,9% of international passengers originating-terminating at Mirabel Airport (18). They definitely constitute a potentiel ridership for a HSGT service.

Given the above segmentation of the market, the next step was to forecast the total number of originating-terminating international air travelers in each of these groups, for each year of the planning horizon. Base data and forecasts from Reference 19 were used and are shown in Table 1-3.

As for connecting air passengers, it was assumed that, upon introduction of HSGT services, all connecting air services between Mirabel and Ottawa would be descontinued. As a result, connecting all travelers would shift to the HSGT service.

1.4 HSGT Traffic Estimates

Five types of traffic could be attracted to a Montreal - Mirabel - Ottawa HSGT service from the total demand described in the previous section. They are:

- intercity traffic: travelers using the HSGT as a line-haul mode for intercity travel between Ottawa and Montreal;
- airport traffic : air travelers using the HSGT as an airport access mode, whether from/to Montreal or Ottawa;
- through traffic : travelers using the HSGT between Montreal and Ottawa as a leg of a longer trip in the Quebec - Windsor corridor;
- induced traffic : persons traveling on the HSGT that would not have made their trip in its absence;
- commuter traffic : residents of the Montreal region using the HSGT as a commuter service between Montreal and Mirabel (and intermediate points if any) for a variety of purposes excluding airport access.

To capture a greater proportion of potential traffic, the Montreal-Mirabel-Ottawa HSGT service should stop at a suburban station west of Montreal: since numerous intercity travelers reside in the Lakeshore and West Island areas, they might not be willing to backtrack to downtown Montreal to board the system. It will be assumed that a suburban station exists and is conveniently located in the West Island. Intercity riders attracted to the system through a suburban station will not be estimated separately however.

1.4.1 Intercity Traffic: Available Forecasts

Past modal shares, based on observed travel demand, are shown in Table 1-4. Common carriers capture between 25 and 30% of total demand; therefore, the modal share for automobile is 70 to 75%. Furthermore, a shift can be observed, from 1969 to 1982, as to how this 25% is distributed between common carriers.

During that period, the air share decreased from 8 to 4% (of the common carrier traffic), the bus share increased from 36% to 59%, while the rail share declined from 56% to 34%. This shift can be explained by three reasons: increases in the air fare, significant improvements in the bus service (resulting from the introduction of express services and the construction of Expressway 417 in Ontario), and a progressive reduction of the rail service.

The estimated modal split for 1982 is shown again in the first row of Table 1-5. As for the future, the projections by Transport Canada's Strategic Planning Group (Table 1-2) provide estimates of future modal shares under an assumption of no major changes in transportation systems. These estimates are also shown again, in the second horizontal block in Table 1-5.

An indication of the impact of a new technology is contained in the STOL Study (6). The modal split forecast is shown in the third row of Table 1-5. STOL shows a significant penetration of the CTOL market, but little impact on the automobile market.

In the case of a future HSGT, there are good reasons to believe that there would be a noticeable and possibly significant penetration of the automobile market, especially in its business segment: the time savings associated with a HSGT would, for many, outweigh the inconvenience of not having an automobile in the destination city.

Table 1-4

Observed Modal Split for Montreal-Ottawa Intercity Travel

Year	Modal Share			
	Air	Rail	Bus	Auto
1969	2%	14%	9%	75%
1973	3%	7%	19%	71%
1976	3%	5%	21%	71%
1982	1%	10%	17%	72%

Note: Data from Tables 1-2 and 1-1.
Air share estimated for 1969 and 1973.

Business bus travelers using that mode chiefly for its convenience could be expected to shift to HSGT in a not insignificant proportion. The same would hold true for air travelers, to a lesser extent, however.

Whatever modal shift is assumed in estimating the future intercity traffic for HSGT, two conflicting factors must be analyzed: the additional travel convenience of a HSGT (reduced travel time, increased frequency vis-a-vis air or rail) as well as the additional cost of its ticket. This is because no new system requiring vast outlays of public funds could be implemented unless principles of full cost recovery were followed in setting its fare policy.

A comprehensive evaluation of these factors requires an in-depth analysis which is beyond the scope of the present study. Again, one must resort to published or unpublished modal split forecasts, which are even fewer in number than the already rare travel demand forecasts discussed in Section 1.3.

A very useful source, which explicitly considers increases both in convenience and fare, is the Alternatives to Air Study (5). Although it studies the full Quebec-Windsor Corridor, it presents separate data and forecasts for the Montreal-Ottawa travel market.

That study considers three HSGT modes: a 200 km/h "Intermediate Speed Rail" (ISR) requiring small capital expenditures, a 250 km/h "High Speed Rail" (HSR) requiring significant capital outlays, and a 450 km/h Maglev requiring a capital investment almost double that of the one for HSR. The corresponding modal shares are shown in Table 1-5.

As could be expected, given the short distance between Montreal and Ottawa, the (much) higher fare for Maglev far ouweighs its (somewhat) greater time savings. As a result, HSR obtains 19,9% of the market and Maglev 15,3%, under a "normal" scenario (5, Tables 2-18 and 2-16).

Table 1-5

Modal Share Estimates for Intercity Travel

Scenario	Modal Share (%)				
	Air	STOL	Rail	Bus	Auto
Existing 1982 (1)	1,4	-	9,7	17,2	71,7
Strategic Planning Projection (2)					
1986	1,4	-	10,5	17,2	70,8
1991	1,5	-	11,7	17,1	69,8
2001	1,7	-	14,2	16,8	67,3
STOL Scenario (3)	0,9	2,6	8,6	16,9	71,0
CIGGT Projections (4)					
ISR (200 km/h)	2,1	-	19,2	12,1	66,6
HSR (250 km/h)	1,1	-	19,9	12,9	66,1
Maglev (450 km/h)	0,5	-	15,3	16,6	67,6

Notes:
(1) From Table 1-4.
(2) From Table 1-2.
(3) From STOL Demonstration Project (6, 7).
(4) Alternatives to Air Study (5).

The reverse would be true between Montreal and Toronto where Maglev and HSR obtain 50,9% and 44,4% of the market, respectively (5, ibid).

Based on the modal share estimates from the Alternatives to Air Study shown in Table 1-5, and on the total travel demand given in Table 1-2, various estimates of intercity traffic for HSGT are given in Table 1-6, in the first block of rows.

VIA Rail constitutes another source of forecasts. VIA's forecast for a 200 km/h train are given in the second block of rows in Table 1-6. Unfortunately, neither the total travel demand nor the economic scenario on which this traffic forecast is based are known with certainty. As the system under consideration by VIA results from the progressive evolution of today's system, it is suspected that the capital outlays required are moderate and the fares correspondingly moderate. These VIA forecasts are based on work done by Transport Canada's Strategic Planning Group.

This group prepared other forecasts for different conditions. Data extracted from such forecasts were supplied to the authors of the present study by TDC; it is shown in the third block of rows in Table 1-6. This forecast was made for economic conditions that seem to correspond reasonably well to CIGGT's Status Quo scenario (5).

This forecast, shown in detail in Table 1-7, is most comparable to the base case for this study, as it considers a new capital-intensive rail system with higher fares. Furthermore, as the travel time reduction is given for each year, one can use its data to estimate the time-elasticity of demand.

From 1980 to 1983, according to this scenario, there would be no travel time reduction and the average annual traffic growth rate would be 4,0% (as in Table 1-2 for rail).

Table 1-6

Estimates of Future Base Intercity Traffic for HSGT

Source	Economic Scenario	System			Modal Share Estimate (%)	Demand and Traffic		
		Type	Speed (km/h)	Fare		Years	Total Demand (1)	Bi-directional traffic (2) (person-trips)
CIGGT (Reference 5)	Status Quo	Rail	200	Moderate	19,2	1986	3 823 300	734 100
						1991	4 266 600	819 200
						2001	5 336 300	1 024 600
		Rail	250	High	19,9	1986	3 823 300	760 800
						1991	4 266 600	849 100
						2001	5 336 300	1 061 900
		Maglev	450	Very High	15,3	1986	3 823 300	585 000
						1991	4 266 600	648 500
						2001	5 336 300	811 100
VIA Rail	Unknown	Rail	200	Moderate	Unknown	1986	?	285 800
						1991	?	1 168 700
						2001	?	1 369 000
Strategic Planning	Moderate Development after resent Crisis	Rail	250	High	Unknown	1986	?	571 600
						1991	?	1 332 200
						2001	?	1 560 600

Notes: 1. Demand from Table 1-2 for first block of rows
2. Column F times Column H for first block of rows
Data from VIA for second block of rows.
Data from Table 1-7 for third block of rows.

In 1984, there would be a 14% reduction in travel time, followed by an increase in traffic of 53% in excess of the "normal" growth (4% per year): this corresponds to a time elasticity of -3,8, implying a 3,8% increase in traffic for a 1% decrease in travel time.

In 1987, another reduction in travel time would occur; it implies a time elasticity of -4,8 (a 46% net increase for a 9,6% reduction in travel time).

In 1990, an implied elasticity of -1 is predicted (32% net increase in ridership for a 31% travel time reduction): as the travel time reduction increases in importance, the time-elasticity of demand appears to decrease.

1.4.2 Intercity Traffic: Forecasting Method

Based on these observations, the following approach will be used in the present study for forecasting intercity traffic for HSGT:

- the forecasts will be based on the estimated 1982 rail traffic, which results from a Montreal-Ottawa travel time of 125 min; these are given in the second row of Table 1-2;

- from 1982 to 1986 inclusive, rail traffic will grow at 4,5% per year and the rail travel time will not change; from 1986 to 1991, it will grow at 4,3% per year; these are strategic Planning rates (4);

- at the beginning of 1991, a new HSGT system will be introduced such that the reduced Montreal-Ottawa travel time will be 70 min in the case of Rail and 45 min in the case of Maglev;

Table 1-7

Montreal-Ottawa Intercity Traffic
Forecast for a High Speed Rail Service

Years	Bi-directional Annual Person-trips (000s)	Rail Performance Indices		
		Fare	Time	Frequency
1980	294,0	100,0	100,0	100,0
1981	306,0	101,0	100,0	100,0
1982	318,4	102,0	100,0	100,0
1983	331,4	103,1	100,0	100,0
1984	529,4	104,1	86,0	105,2
1985	550,6	105,2	86,0	105,2
1986	571,6	105,2	86,0	105,2
1987	866,4	105,2	77,7	131,5
1988	899,0	105,2	77,7	131,5
1989	932,8	105,2	77,7	131,5
1990	1280,6	178,8	53,3	210,4
1991	1332,2	178,8	53,3	210,4
1992	1386,0	178,8	53,3	210,4
1993	1442,0	178,8	53,3	210,4
1994	1500,2	178,8	53,3	210,4
1995	1560,6	178,8	53,3	210,4

Notes:
1. This data was obtained from TDC; it is derived from a Strategic Planning forecast; it presumes a 250 km/h rail speed.
2. This forecast is based on the assumptions that:
   - travel time for competing modes will remain constant,
   - frequency will remain constant for automobile and air and increase slightly for bus,
   - fare will increase slightly for competing modes (much less than for rail).
3. No through traffic is included.

- the 1991 HSGT traffic will be the 1990 rail traffic plus a normal growth of 4,3%, plus an extra increase in ridership resulting from the time saving;

- the minimum extra increase in ridership due to the introduction of the new mode in 1991 will be such that is corresponds to a time-elasticity of demand of -1; thereafter (beyond 1991) traffic will grow again at 4,3% per year for ten years; then growth will decay in 10 years,

- the maximum extra increase in ridership in 1991 will correspond to an elasticity of -2; thereafter, traffic growth will continue at 4,3% per year, for 10 years, then decay to zero growth in 10 years;

- induced traffic is in excess of traffic calculated by the above method and will be estimated separately (Sub-section 1.4.6).

1.4.3 Intercity Traffic _ Forecasts

In Table 1-8, one will find the forecasts of base intercity traffic to be used as the basis for Rail in the comparative assessment in the present study. Corresponding forecasts for Maglev are given in table 1-9.

For both Maglev and Rail, the traffic forecasts are based on introduction of the HSGT service on January 1, 1991. No improvement on today's rail travel time of 125 minutes is expected to take place until then.

Table 1-8

Forecasts of Base Intercity Traffic for Rail

Mode Characteristics		Traffic Estimates (1000 bi-directional person-trips/year)	
Year	Montreal-Ottawa Travel Time (min)	Minimum	Maximum
1982	125	338	338
1983	125	353	353
1984	125	369	369
1985	125	386	386
1986	125	403	403
1987	125	420	420
1988	125	438	438
1989	125	457	457
1990	125	477	477
1991	70	716	935
1992	70	747	976
1993	70	779	1 017
1994	70	813	1 061
1995	70	848	1 107
1996	70	884	1 154
1997	70	922	1 204
1998	70	962	1 256
1999	70	1 003	1 310
2000	70	1 046	1 366
2001	70	1 091	1 425
2002	70	1 121	1 464
2003	70	1 140	1 489
2004	70	1 152	1 505
2005	70	1 160	1 515
2006	70	1 166	1 522
2007	70	1 168	1 526
2008	70	1 170	1 528
2009	70	1 172	1 530
2010	70	1 173	1 531
2011	70	1 173	1 532

Note: The forecasts were estimated using the data base and method described in sub-section 1.4.2.

Table 1-9

Forecasts of Base Intercity Traffic for Maglev

Mode Characteristics		Traffic Estimates (1000 bi-directional person-trips/year)	
Year	Montreal-Ottawa Travel Time (min)	Minimum	Maximum
1982	125	338	338
1983	125	353	353
1984	125	369	369
1985	125	386	386
1986	125	403	403
1987	125	420	420
1988	125	438	438
1989	125	457	457
1990	125	477	477
1991	45	816	1 095
1992	45	851	1 134
1993	45	888	1 183
1994	45	925	1 234
1995	45	966	1 287
1996	45	1 007	1 342
1997	45	1 050	1 400
1998	45	1 096	1 460
1999	45	1 143	1 523
2000	45	1 192	1 589
2001	45	1 243	1 657
2002	45	1 277	1 702
2003	45	1 299	1 731
2004	45	1 313	1 750
2005	45	1 322	1 762
2006	45	1 327	1 769
2007	45	1 331	1 774
2008	45	1 333	1 777
2009	45	1 335	1 779
2010	45	1 336	1 780
2011	45	1 336	1 781

Note: The forecasts were estimated using the data base and method described in sub-section 1.4.2.

1.4.4 Airport-Related Traffic Forecasts

Given that they are susceptible to be attracted to a HSGT service, in what proportion will air travelers effectively use Rail or Maglev when it becomes available? The latest complete modal split data for airport access was obtained in a 1972 survey (11); it is shown in the first block of rows in Table 1-10 for reference.

Estimates of HSGT traffic are given in the lower portion of Table 1-10 They were derived as follows, starting with the potential demand given in Table 1-3.

In the case of Rail, it was assumed that, for passengers originating in downtown or the West Island, 35% of present taxi users would be attracted to the system, in addition to 30% of auto users. Corresponding estimates for access mode split are shown across "Montreal Downtown" and "West Island" rows in the second block of rows in Table 1-10.

The attraction to Maglev would be higher: it was assumed that 70% of present taxi users, as well as 40% of auto users will switch to Maglev. The corresponding results are shown in the third block of rows in Table 1-10.

In addition, it is presumed that the Montreal - Mirabel and Dorval - Mirabel bus services are discontinued and all O-T air travelers presently using these services switch to the HSGT, as well as all air travelers now using "other" modes.

As for passengers originating in Ottawa and presently using the bus, it is expected that the majority (70% or 80% was assumed, respectively) will switch to the HSGT. The use of taxi as well as "other" modes to reach Mirabel from Ottawa by land would vanish, and the auto market would be significantly penetrated: switch from auto to HSGT was assumed to be 30% for Rail and 40% for Maglev. Estimated modal splits are shown in the last row in the second and third blocks of rows in Table 1-10 under "Ottawa".

Table 1-10

Modal Split for Airport Access to Mirabel
(Originating-Terminating Air Passengers Only)

Scenario	Origin or Destination (Percent of Total O.T.)	Airport Access Mode Based on the 1972 Survey[1] (%)				
		Rail	Bus	Taxi	Auto	Other
Existing Modes	Montreal Downtown					
	Zone 3 (14,2%)	-	17	26	54	3
	Zone 4 (15,2%)	-	2	16	77	5
	Zone 9 (7,4%)	-	1	7	91	1
	Weighted average	-	8	18	71	3
	West Island					
	Zone 5 (7,7%)	-	3	17	77	3
	Zone 6 (7,3%)	-	3	9	88	0
	Weighted average	-	3	13	82	2
	Ottawa (7,9%)	-	41	1	55	3
		Assumed Access Mode upon HSGT Implementation[2] (%)				
Rail	Montreal Downtown	38	0	12	50	-
	West Island	35	0	8	57	-
	Ottawa	50	12	0	38	-
Maglev	Montreal Downtown	52	0	5	43	-
	West Island	47	0	4	49	-
	Ottawa	59	8	0	33	-

Notes: 1. Data from Reference 11.
2. Resulting from method explained in Sub-Section 1.4.3.

Based on the future air travel demand (shown segregated by origin-destination in Table 1-3) and the future access mode split (given in Table 1-10), it is possible to estimate the number of originating-terminating air travelers that would predictably use the HSGT for airportaccess to Mirabel: it is a simple matter of distributing the future airport-related demand between access modes. The result is shown in Columns 3, 4, 7 and 8 in Tables 1-11 and 1-12 for Rail and Maglev, respectively.

There are, in addition, two other sources of potential riders for the HSGT: air travelers connecting between flights at Mirabel, either directly by plane; and air travelers arriving/departing at Dorval from/to a domestic or transborder flight and taking the bus to/from Mirabel for/from an international flight. The number of connecting passengers was evaluated in the 1977 survey (11).

It is assumed that the proportion of air connections from/to Ottawa and ground connections from/to Dorval to the total number of international originating-terminating travelers at Mirabel will remain constant at 1,84% and 5,17% respectively.

In the case of direct (air) connections, travelers originating from (terminating in) Ottawa are susceptible to being attracted to the HSGT: it is presumed that all will be attracted, based on the assumption that, upon HSGT implementation, air service between Mirabel and Ottawa would be discontinued. The corresponding HSGT traffic estimate appears in Column 8 in Tables 1-11 and 1-12.

As for connections through Dorval, all air travelers, whatever their origin or destination, could be attracted to HSGT through its suburban station. It is presumed that, in 1991, the Mirabel-Dorval bus service is replaced by a shuttle between Dorval and the suburban station. As a result, 85% of air passengers connecting between Mirabel and Dorval, who now use the bus, would, instead, use the HSGT and the new shuttle. The corresponding estimate is shown in Column 5 in Tables 1-11 and 1-12.

The base traffic for HSGT resulting from international air travel is shown in column 10 in Tables 1-11 for Rail and 1-12 for Maglev.

Table 1-11

Forecasts of Base Airport-Related Traffic for Rail

Year	Number of International O.-T. Passengers at Mirabel (x1000)	Number of International Air Passengers Attracted to HSGT (x1000)							
		From/to Montreal	From/to West Island			From/to Ottawa			TOTAL
		Originating/Terminating	Originating/Terminating	Connecting	Total	Originating/Terminating	Connecting	Total	
1991	1 270	178	47	56	103	50	23	73	354
1992	1 292	181	48	57	105	52	24	76	362
1993	1 314	184	49	58	107	53	24	77	368
1994	1 336	187	50	59	109	53	25	78	374
1995	1 359	190	50	60	110	54	25	79	379
1996	1 382	193	51	61	112	55	25	80	385
1997	1 405	197	52	62	114	56	26	82	393
1998	1 429	200	53	63	116	57	26	83	399
1999	1 453	203	54	64	118	58	27	85	406
2000	1 478	207	55	65	120	59	27	86	413
2001	1 503	210	56	66	122	60	28	88	420
2002	1 519	212	56	67	123	61	28	89	424
2003	1 530	214	57	67	124	61	28	89	427
2004	1 536	215	57	67	124	61	28	89	428
2005	1 540	216	57	68	125	62	28	90	431
2006	1 543	216	57	68	125	62	28	90	431
2007	1 545	216	57	68	125	62	28	90	431
2008	1 546	216	57	68	125	62	28	90	431
2009	1 546	216	57	68	125	62	28	90	431
2010	1 547	217	57	68	125	62	28	90	432
2011	1 547	217	57	68	125	62	28	90	432

Table 1-12

Forecasts of Base Airport-Related Traffic for Maglev

Year	Number of International O.-T. Passengers at Mirabel (x1000)	Number of International Air Passengers Attracted to HSGT (x1000)							
		From/to Montreal	From/to West Island			From/to Ottawa			TOTAL
		Originating/Terminating	Originating/Terminating	Connecting	Total	Originating/Terminating	Connecting	Total	
1991	1 270	243	64	56	120	60	23	83	446
1992	1 292	247	65	57	122	61	24	85	454
1993	1 314	251	66	58	124	62	24	86	461
1994	1 336	255	67	59	126	63	25	88	469
1995	1 359	259	68	60	128	64	25	89	476
1996	1 382	264	69	61	130	65	25	90	484
1997	1 405	268	70	62	132	66	26	92	492
1998	1 429	273	71	63	134	67	26	93	500
1999	1 453	278	73	64	137	68	27	95	510
2000	1 478	282	74	65	139	69	27	96	517
2001	1 503	287	75	66	141	71	28	99	527
2002	1 519	290	76	67	143	71	28	99	532
2003	1 530	292	76	67	143	72	28	100	535
2004	1 536	293	77	67	144	72	28	100	537
2005	1 540	294	77	68	145	72	28	100	539
2006	1 543	295	77	68	145	73	28	101	541
2007	1 545	295	77	68	145	73	28	101	541
2008	1 546	295	77	68	145	73	28	101	541
2009	1 546	295	77	68	145	73	28	101	541
2010	1 547	295	77	68	145	73	28	101	541
2011	1 547	295	77	68	145	73	28	101	541

1.4.5 Through Traffic

If a HSGT system was built in Canada, it would in all likelihood not be restricted to a link between Montreal and Ottawa. Rather, it would probably be a link between Toronto and Montreal with intermediate stations in Mirabel, Ottawa, and/or Kingston; perhaps it would also connect Quebec and Windsor. Consequently, a proportion of HSGT passengers between Montreal and Ottawa would be making a longer trip.

Through traffic will be considered to a limited extent only in this study. It will not be considered in the financial evaluation, because the costs of providing the additional infrastructure and service required to attract through-travelers would also have to be entered into the evaluation. Through traffic will be considered in system definition, however, to ensure that each system is designed so as to offer no constraint to future extension.

1.4.6 Induced Traffic

The introduction of a new or improved service always generates an induced demand, consisting of additional trips that would not have been made in the absence of the system. During the STOL demonstration project between Ottawa and Montreal, for instance, induced demand was estimated at 4% of captured ridership (6).

Induction scale factors used in the Alternatives to Air Study (5) are shown in Table 1-13 for reference.

From a review of the litterature (20), it appears that the scale factors for intercity traffic should be 20% for Rail and 30% for Maglev. The CIGGT factors will be used only for airport-related traffic.

Table 1-13

CIGGT Scale Factors for Induced Demand

Origin-Destination	System	
	Rail	Maglev
Montreal - Ottawa	1,00	1,02
Mirabel - Ottawa	1,00	1,00
Mirabel - Montreal	1,04	1,08

Source: Reference 5.

1.4.7 Commuter Traffic

No commuter traffic will be considered for the HSGT, since this system is not designed and, accordingly, would not be priced, to attract and capture such traffic. Inevitably, however, some residents of the Laurentians may find it advantageous for daily or occasional commuting.

1.4.8 Total Traffic

Total traffic expected for HSGT is shown by component in Tables 1-14 and 1-15 for Rail and Maglev respectively. In both cases, estimates are given for 1991 and 2001. For intermediate years, traffic volume was estimated by interpolation. This was done to prepare Figure 1-3 which shows only the total.

In estimating traffic on each leg of the trip, the geographic origin/destination of intercity travelers was taken as 62,5% at the Montreal Terminal and 37,5% at the Suburban Station. This was based on recent surveys, which are discussed in Chapter 3.

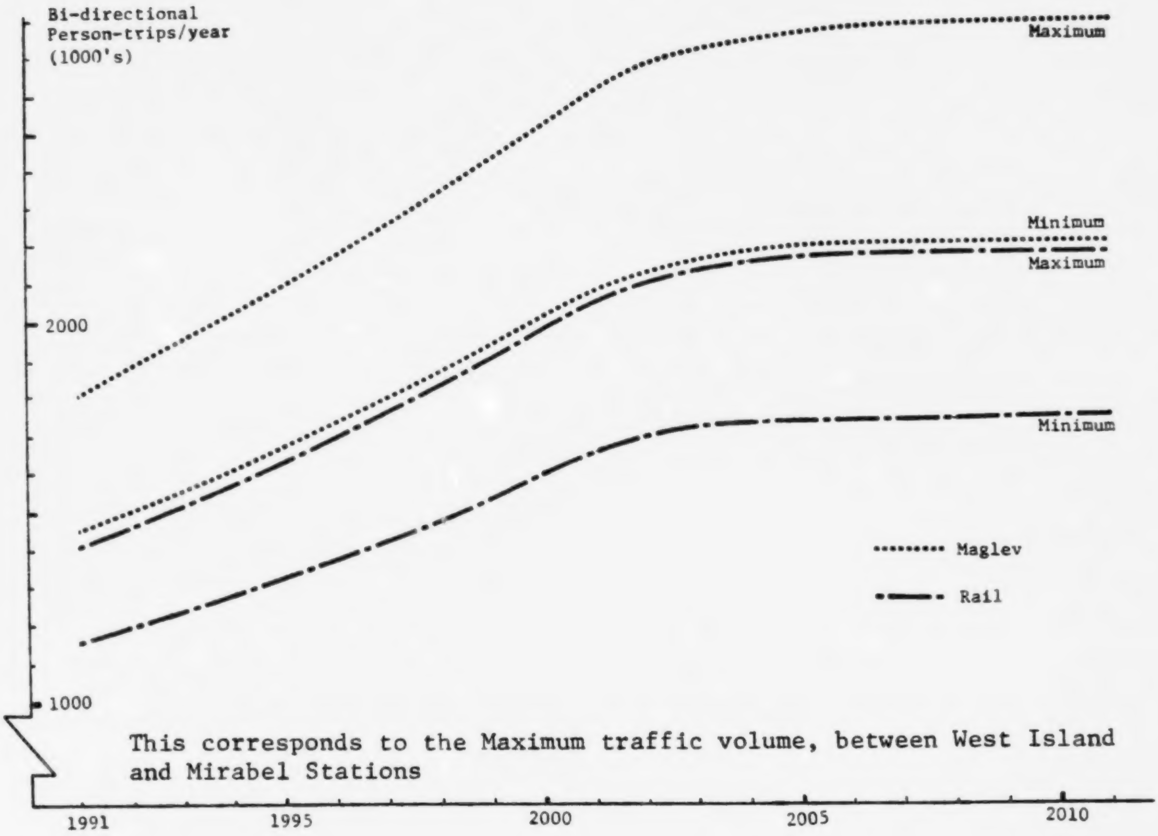


Figure 1-3 Forecasts of Total Future Traffic for HSGT

Table 1-14

Forecasts of Total Traffic for Rail

Year	Link	Traffic Estimate by Type (1000 bi-directional person-trips)							
		Minimum or Maximum	Intercity			Airport			All Types
			Base	Induced	Total	Base	Induced	Total	
1991	Montreal	Minimum	448	90	538	178	7	185	723
	West-Island	Maximum	584	117	701	178	7	185	886
	West-Island	Minimum	716	143	859	281	11	292	1 151
	Mirabel	Maximum	935	187	1 122	281	11	292	1 414
	Mirabel	Minimum	716	143	859	73	0	73	932
	Ottawa	Maximum	935	187	1 122	73	0	73	1 195
1996	Montreal	Minimum	553	111	664	193	8	201	865
	West-Island	Maximum	721	144	865	193	8	201	1 066
	West-Island	Minimum	884	177	1 061	305	12	317	1 378
	Mirabel	Maximum	1 154	231	1 385	305	12	317	1 702
	Mirabel	Minimum	884	177	1 061	80	0	80	1 141
	Ottawa	Maximum	1 154	231	1 385	80	0	80	1 465
2001	Montreal	Minimum	682	136	818	210	8	218	1 036
	West-Island	Maximum	891	178	1 069	210	8	218	1 287
	West-Island	Minimum	1 091	218	1 309	332	13	345	1 654
	Mirabel	Maximum	1 425	285	1 710	332	13	345	2 055
	Mirabel	Minimum	1 091	218	1 309	88	0	88	1 397
	Ottawa	Maximum	1 425	285	1 710	88	0	88	1 798
2006	Montreal	Minimum	729	146	875	216	9	225	1 100
	West-Island	Maximum	951	190	1 141	216	9	225	1 366
	West-Island	Minimum	1 166	233	1 399	341	14	355	1 754
	Mirabel	Maximum	1 522	304	1 826	341	14	355	2 181
	Mirabel	Minimum	1 166	233	1 399	90	0	90	1 489
	Ottawa	Maximum	1 522	304	1 826	90	0	90	1 916
2011	Montreal	Minimum	733	147	880	217	9	226	1 106
	West-Island	Maximum	958	192	1 150	217	9	226	1 376
	West-Island	Minimum	1 173	235	1 408	342	14	356	1 764
	Mirabel	Maximum	1 532	306	1 838	342	14	356	2 194
	Mirabel	Minimum	1 173	235	1 408	90	0	90	1 498
	Ottawa	Maximum	1 532	306	1 838	90	0	90	1 928

Table 1-15

Forecasts of Total Traffic for Maglev

Year	Link	Traffic Estimate by Type (1000 bi-directional person-trips)							
		Minimum or Maximum	Intercity			Airport			All types
			Base	Induced	Total	Base	Induced	Total	
1991	Montreal	Minimum	510	153	663	243	19	262	925
	West-Island	Maximum	684	205	889	243	19	262	1 151
	West-Island	Minimum	816	245	1 061	363	29	392	1 453
	Mirabel	Maximum	1 095	329	1 424	363	29	392	1 816
	Mirabel	Minimum	816	245	1 061	83	0	83	1 144
	Ottawa	Maximum	1 095	329	1 424	83	0	83	1 507
1996	Montreal	Minimum	629	189	818	264	21	285	1 103
	West-Island	Maximum	839	252	1 091	264	21	285	1 376
	West-Island	Minimum	1 007	302	1 309	394	32	426	1 735
	Mirabel	Maximum	1 342	403	1 745	394	32	426	2 171
	Mirabel	Minimum	1 007	302	1 309	90	0	90	1 399
	Ottawa	Maximum	1 342	403	1 745	90	0	90	1 835
2001	Montreal	Minimum	777	233	1 010	287	23	310	1 320
	West-Island	Maximum	1 036	311	1 347	287	23	310	1 657
	West-Island	Minimum	1 243	373	1 616	428	34	462	2 078
	Mirabel	Maximum	1 657	497	2 154	428	34	462	2 616
	Mirabel	Minimum	1 243	373	1 616	99	0	99	1 715
	Ottawa	Maximum	1 657	497	2 154	99	0	99	2 253
2006	Montreal	Minimum	829	249	1 078	295	24	319	1 397
	West-Island	Maximum	1 106	332	1 438	295	24	319	1 757
	West-Island	Minimum	1 327	398	1 725	440	35	475	2 200
	Mirabel	Maximum	1 769	531	2 300	440	35	475	2 775
	Mirabel	Minimum	1 327	398	1 725	101	0	101	1 826
	Ottawa	Maximum	1 769	531	2 300	101	0	101	2 401
2011	Montreal	Minimum	835	251	1 086	295	24	319	1 405
	West-Island	Maximum	1 113	334	1 447	295	24	319	1 766
	West-Island	Minimum	1 336	401	1 737	440	35	475	2 212
	Mirabel	Maximum	1 781	534	2 315	440	35	475	2 790
	Mirabel	Minimum	1 336	401	1 737	101	0	101	1 838
	Ottawa	Maximum	1 781	534	2 315	101	0	101	2 406

References for Chapter 1

1. Research Branch, Canadian Transport Commission, "Intercity Passenger Transport Study", Government of Canada, Ottawa, September 1970.

2. Department of Civil Engineering, Carlton University, Ottawa, "Intercity Passenger Transport Energy Efficiency: Data Base and Case Study", for Strategic Studies Branch, Transport Canada, Ottawa, June 1979.

3. Transportation Development Agency, "Mode Choice for Intercity Passenger Travel Montreal - Ottawa: A working paper", Transport Canada, TP234, Montreal, August 1976.

4. Strategic Planning Group, "Freight and Passenger Forecasts 1981", Transport Canada, TP2957, Montreal, February 1982.

5. Canadian Institute of Guided Ground Transport, Queen's University of Kingston, "Alternatives to Air: A Feasible Concept for the Toronto - Ottawa -Montreal Corridor", Volume One, CIGGT Report 80-4, for Transport Canada, TP 2667, Kingston (Ontario), July 1980.

6. Air Administration, "STOL and Short Haul Air Transportation in Canada", Transport Canada, TP1494, Montreal, July 1978.

7. Research and Development Centre, "Passenger Transportation between Ottawa and Montreal, 1973-1976: An Analysis of the Impact of the Air Transit STOL Demonstration Service on the Passenger Volumes of Other Modes, including the Private Automobile", Transport Canada, TP1409, Montreal, November 1977.

8. Bureau of Management Consulting, "Opportunities for energy conservation in intercity passenger transportation: the Ottawa-Montreal Corridor", Supply and Services Canada, report prepared for the Office of Energy Conservation Department of Energy, Mines and Resources, Montreal, September 1978.

9. Canadian Institute of Guided Ground Transport, Queen's University of Kingston, "Strategic Planning and the Railway Passenger Mode: a critique", CIGGT Report 80-10, Kingston(Ontario), September 1980.

10. Department of Civil Engineering, Carleton University, "Review of Energy Factors in Canadian Intercity Passenger Transportation Policy and Planning Studies", for Strategic Studies Branch, Transport Canada, TP2065, Ottawa, March 1979.

11. Montreal Area Airport System Planning Service, "Montreal Air Passenger Profile Analysis", Study no. 77-01", Air Administration, Transport Canada, Montreal, April 1977.

REFERENCES (Cont'd)

12. Phaneuf, Gravelle, Blain et Associés, "La desserte terrestre des aéroports de Mirabel et de Dorval: scénario no 6-1991", pour l'Administration canadienne des transports de surface, Transports Canada, Montreal, March 1981.

13. Econosult Inc., "Mise en place d'un système de navette à Dorval. Etude de faisabilité", pour le Centre de développement des transports, Transports Canada, TP3763F, Montréal, Août 1982.

14. Statistics Canada, Catalog 51-204.

15. Strategic Planning Group, "Transportation Demand and Oil Use to 1990", Transport Canada, Montreal, February 1982.

16. Cluchey, James P. and Myers, Barry B., "Analysis of Results of Intercity Bus Passenger Surveys on Montreal - Ottawa, Montreal - Toronto and Montreal - Quebec", for Transport Canada, TP2434, Montreal, December 1979.

17. Montreal Area Airport Systems Planning Service Quebec Region, "Montreal Area Airport Statistics Related to Ground Transportation, Study no. 78-01, Air Administration, Transport Canada, Montreal, February 1978.

18. Montreal Area Airport System Planning Service, Special compilation based on 1977 survey data, Air Administration, Transport Canada, Montreal, April 1982. Unpublished.

19. Montreal Area Airport System Planning Service, Preliminary passenger forecasts, Air Administration, Transport Canada, Montreal, November 1982. Unpublished.

20. Shilton, David, "Modeling the Demand for High Speed Train Services", Journal of the Operational Research Society, 33, 8, pp. 713-722, 1982.

This page left blank intentionally.

2. TECHNOLOGY DEFINITION

The purpose of this chapter is to present the key technical parameters that characterize each of the two technologies to be compared. These parameters are those that will determine system requirements, configuration, and performance.

One of these two technologies was already identified when starting the study: the TransRapid high speed magnetic levitation system presently being developed in the Federal Republic of Germany. In this case, technology definition is relatively straightforward and consists of listing the key technical parameters of that technology, and then establishing the approriate value for each.

In the case of the high speed rail, the situation is not as clear. All that is specified by the terms of reference is that it is to be a "conventional technology" with a maximum operating speed of 200 km/h. It then becomes necessary to select, amongst various conventional technologies, the most appropriate for the comparison, before identifying and quantifying its key technical parameters.

The parameters of the Maglev technology will be presented in the first section of this chapter, together with a brief description of the system. The identification of the Rail technology to be compared with the TransRapid system will be discussed in the second section of the chapter; its key parameters will be presented in the third section.

2.1 Key Parameters of the Maglev Technology

The objective of this section is to provide a brief description of the Maglev system considered in this study. That description will outline its key technical parameters, its physical configuration, and its functional characteristics. The description will successively cover the following three sub-systems: vehicle, propulsion, and infrastructure.

The Maglev vehicle analyzed is identical to the TransRapid TR 06 vehicle developed for testing at the Emsland Test facility. As shown in Figure 2-1, it is 54 m long, 3,7 m wide, and 4,2 m high; it is made-up of two identical sections that can be uncoupled for maintenance. This bi-directional vehicle (each half or section has a cockpit) constitutes the basic operating unit and has all the necessary equipment for independent operation. Each half of this vehicle contains 96 seats.

Between the two end sections of the basic operating unit can be added one to four additional intermediate sections, bringing the total capacity of the consist up to 576 seats.

Levitation and guidance forces for the vehicle are provided by controlled electromagnets located in the four bogies of the vehicle and in the guideway, which is enveloped by the vehicle (Figure 2-2).

Propulsion is provided by a synchronous linear motor, the active long stator of which is embedded in the guideway. At a steady speed of 400 km/h, this propulsion system provides a mechanical power equivalent to 4,8 MW; the mechanical energy required for propulsion, levitation, and guidance is 90 Wh/seat-km on level tangent at 400 km/h.

The maximum speed is 400 km/h; in urban areas, the speed would not exceed 200 km/h. In normal service, the maximum acceleration and deceleration rates are 1,0 m/s^2, being limited by comfort considerations, given a maximum superelevation of 12°.

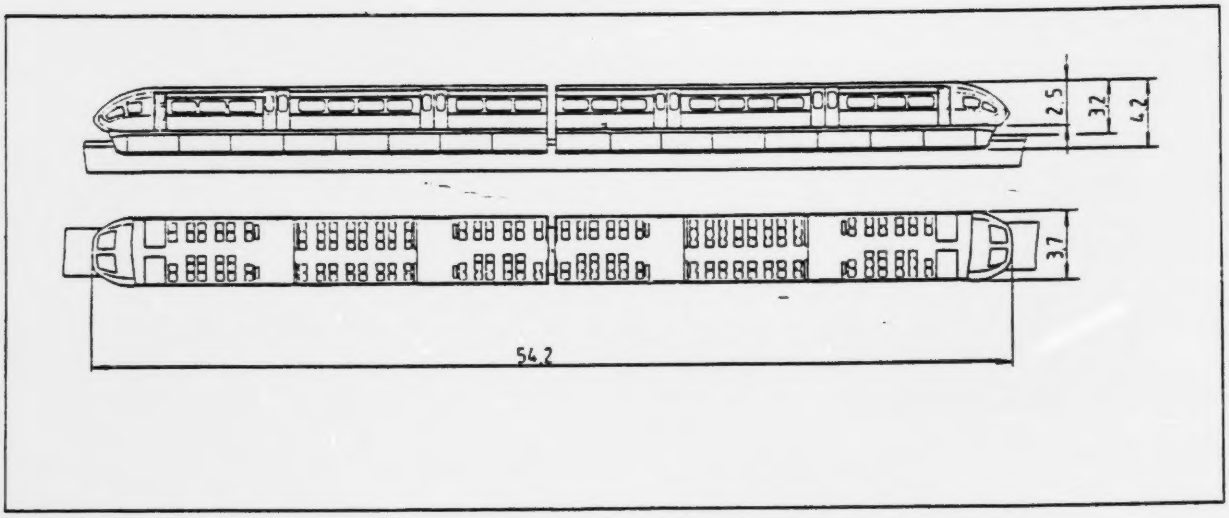
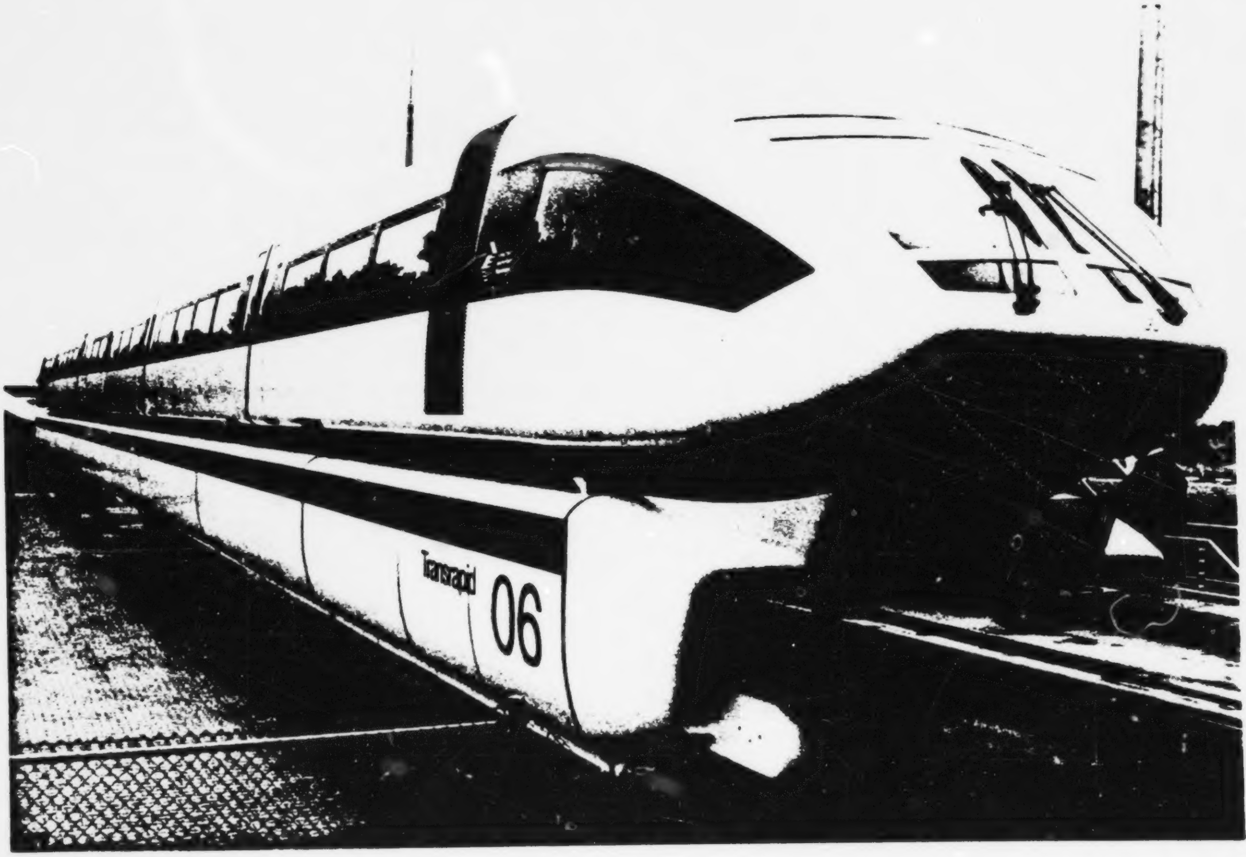

2.5
3.2
4.2
3.7
54.2

Figure 2-1 Maglev Vehicle: General View and Main Dimensions


Transrapid
06

To achieve and maintain the stringent positional tolerances necessary for efficient magnetic levitation and propulsion, the Maglev vehicle is carried on a rigid structure. The standard configuration for this structure is a prestressed concrete box girder which is 25 m long and 1,8 m deep.

This standard beam is usually supported on concrete piers (Figure 2-3). For an elevated guideway, the clearance between the terrain and the underside of the beam is normally 5 m: this has proven to be the minimum-cost configuration in urban areas, as the need for grade-separation structures is eliminated.

The standard beam can also be supported on slabs for implementation in a cut in a tunnel (Figure 2-4) or at grade (Figure 2-5). Guideway beams have also been designed in lengths of 36 and 72 m, so as to cover a wide range of applications without the need to design special structures. Guideway beams can also be made of steel.

The levitation and propulsion equipment of the Maglev guideway was designed to allow bi-directional operation. Consequently, the guideway can be built single or double depending on traffic requirements.

Two types of turnouts have been developed for the Maglev system: a "yard" turnout for stations and other low speed territory and a "line" turnout for high speed. In a straight direction, the vehicle can traverse both types of turnouts at 400 km/h. When branching, speed is restricted to 100 km/h on a yard turnout and to 200 km/h on a line turnout.

The geometry of the guideway is dictated by topographical and technical constraints and comfort requirements (maximum lateral and vertical acceleration and jerk). Based on a maximum acceleration of 1,0 m/s^2, the minimum radius of horizontal curves is 4 000 m and that of vertical curves, 25 000 m. The maximum gradient is normally 3,5%

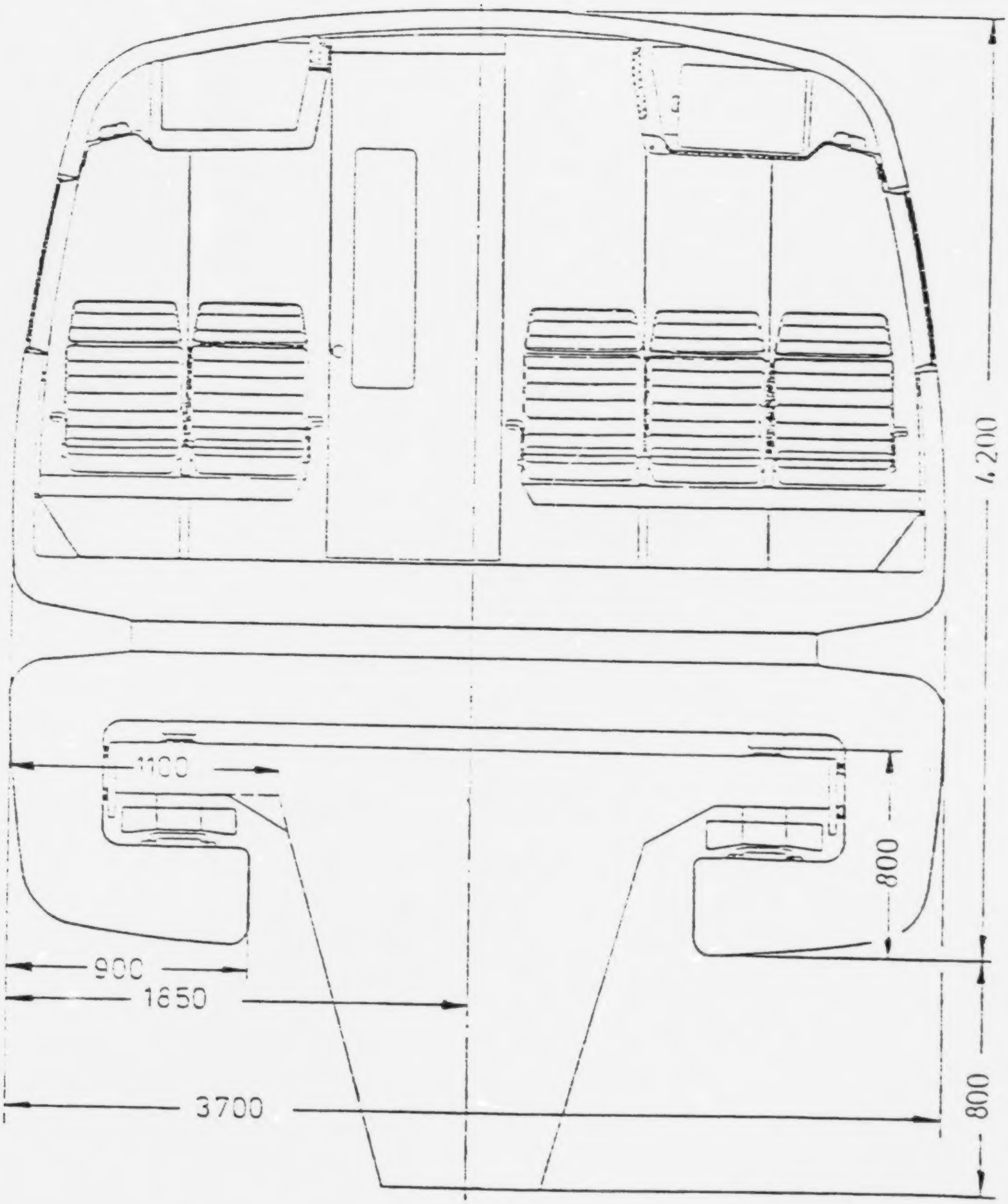
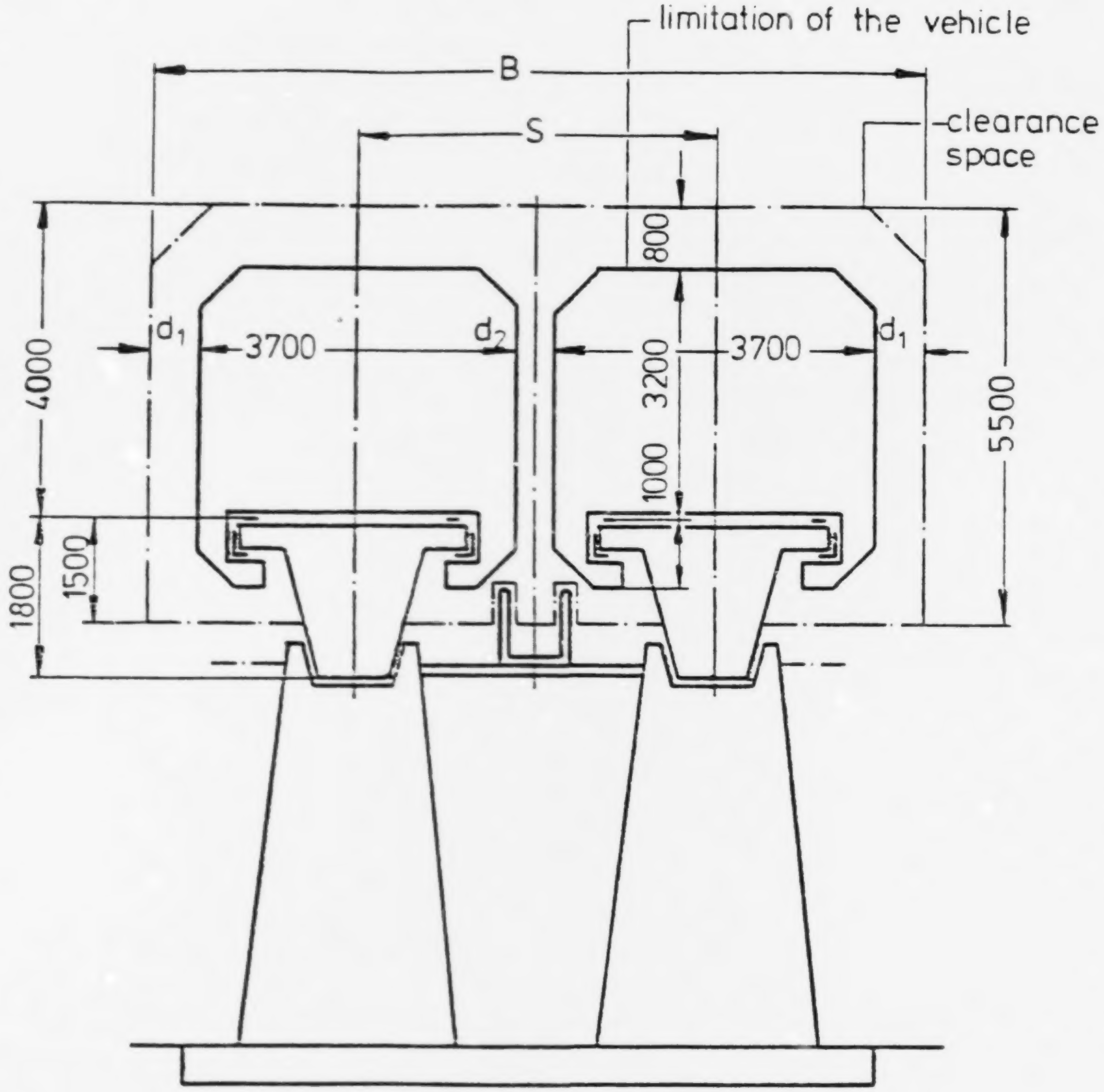

1100
800
900
1650
3700
800
4200

Figure 2-2 Cross-Section of the Maglev Vehicle on the Guideway


limitation of the vehicle
B
S
clearance space
800
4000
d_1
3700
d_2
3200
3700
d_1
5500
1000
1800
1500

	v (km/h)		
	200	300	400
B (m)	9,10	9,70	11,80
S (m)	4,20	4,40	5,10
d_2 (m)	0,60	0,80	1,50
d_1 (m)	0,50	0,70	1,40

Figure 2-3 Maglev Guideway Clearances for Elevated Construction

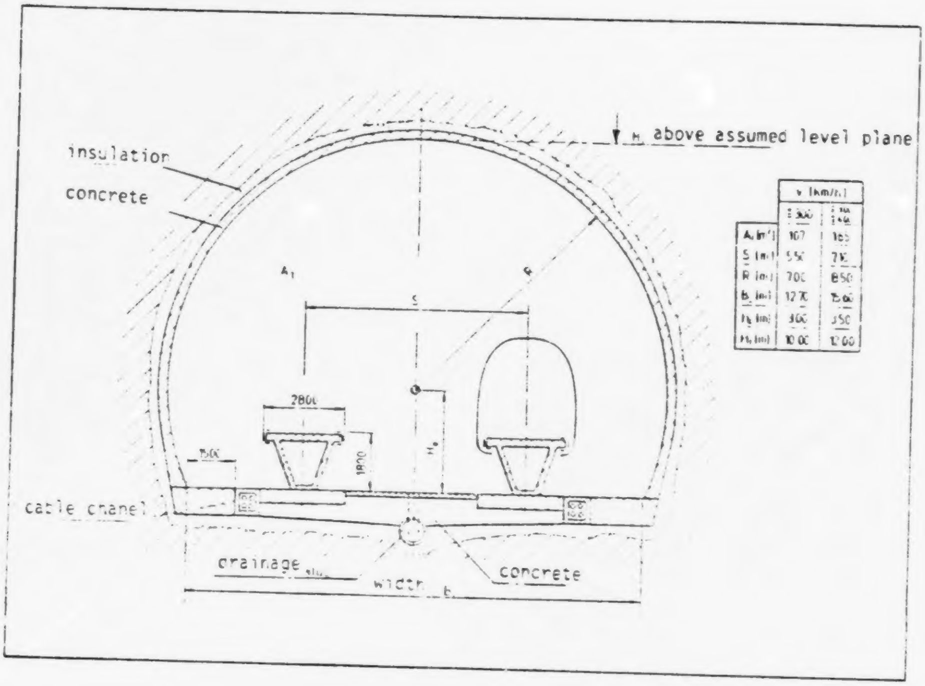

H above assumed level plane
insulation
concrete
v [km/h]
A
S
R
2800
1800
cable chanel
drainage
width
concrete

Figure 2-4 Maglev Guideway in a Tunnel

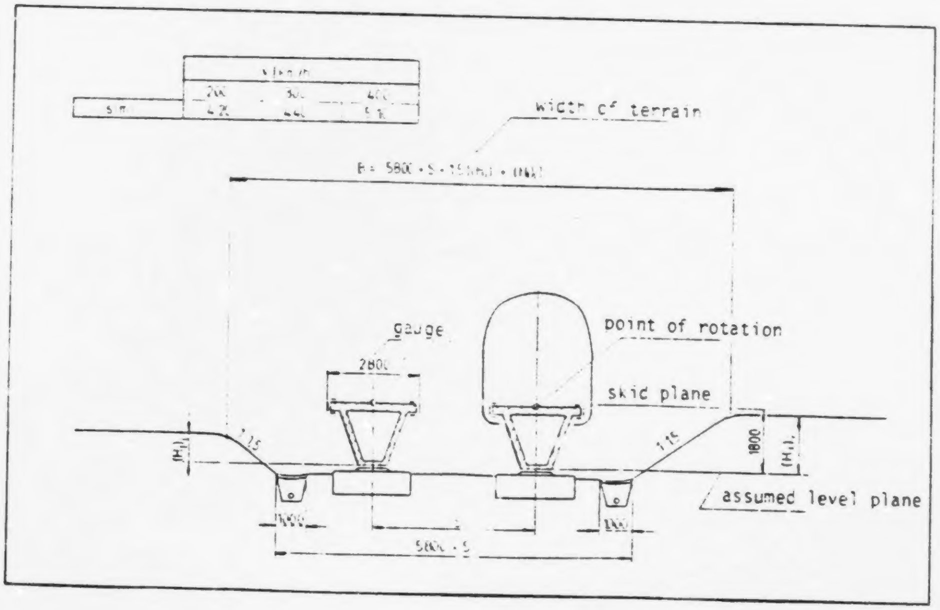

width of terrain
gauge
2800
point of rotation
skid plane
1:15
1800
assumed level plane
5800 + S

Figure 2-5 Maglev Guideway in Cut or at Grade

at maximum speed; for short distances, the maximum gradient could be as high as 5%. Sinusoidal transition curves are provided in both horizontal and vertical curves and the maximum superelevation is 12°.

Key technical parameters of the Maglev system are summarized in Table 2-1. More information will be found in Appendix B.

Table 2-1

Technical Parameters of the Maglev Technology

Technical or performance factor	Corresponding Technical Parameters	
	Identification	Value
Dimensions and Clearances	Length of normal train consist..................	54,0 m
	Height of coach top over........................	3,2 m
	Maximum train width (coach).....................	3,7 m
	Dynamic overhang on minimum radius curve at Vmax.	N.A. m
	Minimum height, rail to overhead conductor......	N.A. m
	Maximum height, rail to overhead conductor......	N.A. m
	Minimum vertical clearance at Vmax	0,8 m
Speed	Design maximum..................................	400 km/h
	Operating maximum on level tangent(Vmax)........	400 km/h
	Test or trial maximum (Emsland)	250 km/h
	Maximum straight over a turnout	400 km/h
	Maximum, across a crossover (on line)	200 km/h
Acceleration	Design maximum..................................	1,0 m/s^2
	Average in service(0 to Vmax)...................	0,55 m/s^2
	Time to reach.........Vmax from 0 km/h..........	320 s
	Distance to reach ....Vmax from 0 km/h..........	23 000 m
	Time to reach ....75% Vmax from 0 km/h......	160 s
	Distance to reach ....75% Vmax from 0 km/h......	8 200 m
Deceleration (Vmax to 0 km/h)	Average service braking rate....................	0,75 m/s^2
	Service braking time............................	150 s
	Service braking distance........................	8 800 m
	Maximum emergency braking rate..................	3,5 m/s^2
	Emergency braking time..........................	30 s
	Emergency braking distance......................	3 500 m
Curveability	Minimum radius of horizontal curve (Vmax, 1,0 m/s^2)	4 000 m
	Minimum radius of horizontal curve at 75% Vmax..	2 300 m
	Minimum radius of horizontal curve in yard......	500 m
Gradeability	Normal maximum gradient at Vmax.................	3,5 %
	Absolute maximum gradient at Vmax...............	5,0 %
	Minimum radius of vertical curve (crest)........	25 000 m
	Minimum radius of vertical curve (through)......	25 000 m
Train consist	Prime Mover.....................................	2
	Normal number of coaches........................	0
	Maximum number of coaches.......................	4
	Number of axles of normal consist-prime mover ..	N.A.
	Number of axles of normal consist-each coach ...	N.A.
Weights	Tare weight of normal consist...................	102 t
	Number of passengers............................	192
	Total weight with full passenger load...........	122 t
	Lineal loading - prime mover	2,26 t/axle
	Lineal loading - coach	2,26 t/axle
Power	Number of motors per consist....................	N.A.
	Nominal rating of each motor....................	N.A. kW
	Effective rail power of normal consist..........	4 800 kW
	Effective hotel power of normal consist.........	200 kW
	Power-to-weight ratio...........................	41 kW/t
	Tare weight per passenger.......(t/passenger)...	0,77
	Energy consumption per seat-km at full load at maximum speed	64 (kWh/ seat-km)

2.2 Selection of a Rail Technology

The emphasis in this comparative assessment should be on evaluating the relative merits of using either steel wheels on steel rails or magnetic levitation techniques for support and guidance of vehicle. The rail technology should be selected with this objective in mind.

But this selection must also take into account in addition the following constraints and/or concerns:

- the rail technology should be capable of providing a level of service that is effectively comparable to that offered by the Maglev technology (otherwise the comparison would be more between two levels of service than between two technologies);
- the rail technology should have infrastructure requirements that are of the same nature as those of Maglev (otherwise the comparison would be between two greatly differing levels of investment rather than between two technologies);
- the rail technology selected should reflect the time frame for implementation. As the maglev technology can definitely not be implemented in a revenue system before 1990, and possibly not even before 2000, the rail technology should be comparably up-to-date;
- the rail technology should conform to VIA Rail's overall concept specification,
- the rail technology should be such that its costs can be estimated with reasonable degrees of accuracy and reliability;
- the rail technology should preferably be Canadian, so that the comparison would also yield insight into the advantages of importing foreign technology.

The above-listed requirements are unfortunately conflicting to a significant extent. For example, the maximum operating speed for Maglev is 400 km/h; although the absolute rail speed record in Canada, captured by the Turbotrain in a trial run, is 275km/h, the normal operating speed is presently in the order of 115 to 150 km/h only.

Some significant development of the current Canadian rail technology must obviously be assumed, but this should be done without unduly sacrificing the reliability of the cost estimates.

One way to achieve this objective is to define the rail technology piecemeal, by subsystem: guideway, tracks, power supply, signalling, and rolling stock. This procedure will be used.

To provide the rail system with a high average speed, the geometry of the track should be designed to permit a maximum speed of 250 km/h, to be maintained everywhere on the line except in special cases or in urban areas. To provide, at that speed, the same level of safety as the Maglev system, the right-of-way should not be interrupted by any level crossings of roads or tracks.

To ensure that the high average speed achievable with the maximum operating speed of 200 km/h specified can be consistently maintained, the rail system will be operated on exclusive tracks: only service vehicles will use the tracks, at times selected to minimize delays.

Since it is very difficult to operate consistently at 200 km/h with diesel equipment without adverse effects to the track, most high speed rail systems presently in operation are electrified. The rail technology selected should accordingly be electric, with high-voltage single-phase power supply from an overhead catenary. The signalling system should be designed to ensure the highest level of safety at the maximum operating speed.

All these elements of the rail system could, with foreign assistance in specific areas, be designed and engineered in Canada. They could also be manufactured and/or built in Canada, by Canadian firms.

As for rolling stock, in order to obtain reliable cost estimates, and taking into account the sums already invested by Transport Canada in its development, the LRC train was suggested as a logical base from which to define the vehicle for the rail technology.

Henceforth in this report, the capitalized "Rail" will be used to refer to the rail system defined hereinafter (Section 2.3) for comparison with the Maglev system.

2.3 Key Parameters of the Rail Technology

The objective of this section is similar to that of Section 2.1, i.e. to provide a brief description of the Rail technology, outlining its key technical parameters. But a suitable system must first be selected. This has been done for most sub-systems in the preceding section. The problem remains difficult for rolling stock, as no Canadian rail vehicle exists or is now being developed, that meets all the criteria formulated.

Two types of vehicles, both starting from available Canadian technology, could be developed that would meet most of these performance criteria: an electrified version of the LRC train or an electrified version of the Turbo Train. Unfortunately, any estimation of their cost within the framework of this study would be highly speculative and, furthermore, would have to be based on some amount of preliminary design, which would inevitably be subject to question. For instance, the power supply, and conditioning equipment and the traction motors and vehicle performance would have to be specified to some degree: this would require analyses that are well beyond the scope of this study.

A compromise solution would be a vehicle that meets most of the criteria and is sufficiently defined that its cost can be estimated with reasonable degrees of accuracy and reliability. A suitable compromise, for analysis purposes, appears to be a train made-up of LRC coaches pulled by an electric locomotive. The last coach would be equipped with full controls for bi-directional operation and the consist would be operated, serviced, and maintained as a permanently-coupled unit.

The LRC coach, shown in Figure 2-6, is 26 m long, 3,20 m wide, and 3,65 high above the rail. A consist of five coaches, which includes a bar and a buffet, offers 385 seats. If pulled by an appropriate locomotive, the consist could be operated at 200 km/h. In normal service, the average acceleration would be 0,27 m/s^2 and the average braking rate, 0,6 m/s^2. Each coach is suspended on two conventional bogies, resulting in an axle loading of 11 t. The tilting mechanism would not be needed on straight track in rural areas. Depending on the geometry of the line and the maximum speed allowed in urban areas, the tilting mechanism could be installed or omitted.

Propulsion for the train could be provided by an AEM-7 locomotive, for instance. Based on a Swedish design, this locomotive is now supplied by the Electro-Motive Division of General Motors Corporation. It is operated by Amtrak in the Northeast Corridor. This B-B locomotive weights 91 t and provides a diesel equivalent power of 7000 hp; it is now geared for a maximum operating speed of 201,6 km/h. Power at 25 kV 60 Hz would be provided by an overhead catenary.

The track would be used exclusively for high speed passenger service. To ensure a high degree of comfort at the speeds envisioned, the track would be built of continuously-welded rail, generally at ground level (to reduce costs). The right-of-way would be fully grade-separated from roads and other tracks (to increase safety).

As in the case of the TransRapid, the geometry of the track will be dictated by topographical and technical constraints as well as by comfort requirements. With a lateral acceleration limited to 1,0 m/s^2, and a 6° superelevation, the minimum radius of horizontal curves is 2400 m at 200 km/h and that of vertical curves, 20000 m. The maximum gradient at that speed is 2,5%.

Key technical parameters of the Rail system are given in Table 2-2.

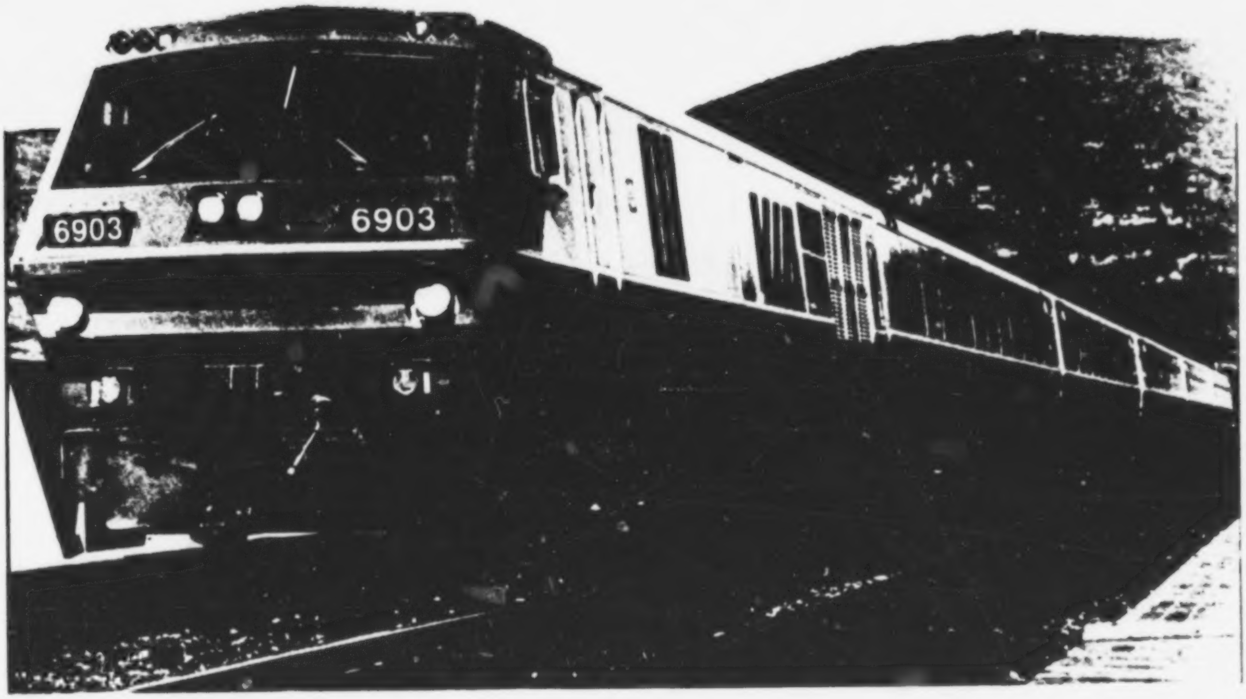

6903
6903
VIA

Figure 2-6 LRC Coach: General View

Table 2-2

Technical Parameters of the Rail Technology

Technical or performance factor	Corresponding Technical Parameters	
	Identification	Value
Dimensions and Clearances	Length of normal train consist	145 m
	Height of coach top over rail	3,65 m
	Maximum train width (coach)	3,20 m
	Dynamic overhang on minimum radius curve	m
	Minimum height, rail to overhead conductor	m
	Maximum height, rail to overhead conductor	m
	Minimum vertical clearance	m
Speed	Design maximum	200 km/h
	Operating maximum on level tangent(Vmax)	200 km/h
	Test or trial maximum	km/h
	Maximum over a turnout	200 km/h
	Maximum across a crossover	150 km/h
Acceleration	Design maximum	0,6 m/s^2
	Average in service(0 to Vmax)	0,27 m/s^2
	Time to reach.........Vmax from 0 km/h	206 s
	Distance to reach ....Vmax from 0 km/h	7 590 m
	Time to reach ....75% Vmax from 0 km/h	154 s
	Distance to reach ....75% Vmax from 0 km/h	3 215 m
Deceleration (Vmax to 0 km/h)	Average service braking rate	0,6 m/s^2
	Service braking time	92 s
	Service braking distance	2 560 m
	Maximum emergency braking rate	2,5 m/s^2
	Emergency braking time	44 s
	Emergency braking distance	1 234 m
Curveability	Minimum radius of horizontal curve at Vmax	2 400 m
	Minimum radius of horizontal curve at 75% Vmax	2 060 m
	Minimum radius of horizontal curve in yard	76 m
Gradeability	Maximum gradient at Vmax	2,5 %
	Maximum gradient on line	2,5 %
	Minimum radius of vertical curve (crest)	20 000 m
	Minimum radius of vertical curve (through)	20 000 m
Train consist	Prime Mover	1
	Normal number of coaches	5
	Maximum number of coaches	7
	Number of axles of normal consist-prime mover	4
	Number or axles of normal consist-each coach	4
Weights	Tare weight of normal consist	312 t
	Number of passengers	385
	Total weight with full passenger load	339 t
	Axle loading - prime mover	23 t/axle
	Axle loading - coach	11 t/axle
Power	Number of motors per consist	2
	Nominal rating of each motor	2 600 kW
	Effective rail power of normal consist	4 500 kW
	Effective hotel power of normal consist	500 kW
	Power-to-weight ratio	13,3 kW/t
	Tare weight per passenger.......(t/passenger)	0,81
	Energy consumption per seat-km at full load at maximum speed	46 (kWh/seat-km)

3. PERFORMANCE SPECIFICATION

The objectives of this chapter are to present and justify the service standards that will be specified for the Montreal - Mirabel - Ottawa HSGT service.

This specification will be done in three steps. First, the target market will be identified, based on the traffic forecasts presented in Section 1.4. The target market is discussed in the first section of the present chapter.

Second, the needs of the target market will be assessed. To meet these needs, a service strategy will be formulated for the HSGT. This strategy will be expressed through a series of functional requirements that each technology should meet in order to provide a quality of service that will effectively attract the segment of the market previously identified as the target. This is the object of the second section of the chapter.

Third, a system performance will be specified that corresponds to the service strategy and in effect achieves it. That performance may be seen as the set of service standards that the system must meet in order to fulfill the functional requirements and thus effectively attract the target market. This is discussed in the third and last section of the chapter.

The performance specification will be the same for both technologies. Each technology, however, can exceed some of the common requirements, as long as it meets them all, in doing so, that technology would thus provide additional benefits, which could possibly outweigh additional costs if any that are associated with its superior performance.

3.1 Identification of the Target Market

The nature of the potential market for a HSGT service between Montreal, Mirabel, and Ottawa, has been summarily described in Section 1.4. That description suggested that this potential market could be disaggregated as follows:

- intercity traffic,
- airport traffic, consisting of:
  - airport access from Montreal to Mirabel;
  - airport access from Ottawa to Mirabel (currently by a ground mode or a connecting flight),
  - passengers connecting (now by bus) between one flight at Dorval and another at Mirabel,
- through traffic,
- induced traffic,
- commuter traffic.

The identification of the specific target in the market will proceed by progressively eliminating those market segments that could not or should not be the target for a HSGT service, as discussed below.

Commuter traffic cannot be considered a target market. A HSGT is designed primarily to offer high speed service between its terminals. This implies a very limited number of intermediate stations as, however high the cruising speed is, the addition of a station inevitably reduces the average speed between terminals, sometimes significantly, thus defeating the very purpose of the HSGT service. Conversely, a commuter service requires a relatively high density of stations (number of stations per km) to provide an adequate geographic coverage, this is in direct opposition to a HSGT service. Furthermore, the provision of a high speed service requires a high performance system that is expensive to implement and operate. If its costs are to be fully recovered, the fare for a short trip will be relatively high and probably too expensive for daily or regular use of the service for commuting to work.

The induced traffic cannot either be the target market, as its nature is not known with certainty until the system is implemented.

Through traffic presents a special problem. As it originates before Montreal and/or terminates beyond Ottawa (or the converse), it cannot be the basis for specifying the quality of service for a system that links only those two cities. On the other hand, if it is decided to implement a HSGT on that link, the same technology will in all likelihood be used throughout or at least in a signicant proportion of the Canadian Corridor, and not only between Montreal and Ottawa. As a consequence, the requirements associated with through traffic cannot be ignored altogether when considering only the Montreal - Ottawa link. They should be considered particularly relevant when specifying the size or capacity of some system elements, so that partial or total redesign and/or reconstruction is not necessary when the service is eventually extended beyond the Montreal-Ottawa link.

The airport traffic cannot, any more than the above three market segments, be a prime target for the HSGT service, there are several reasons for this. First, although travelers could use the HSGT between Mirabel and Ottawa, as well as between Montreal and Mirabel, traffic on the latter portion would be significantly more important than on the former, resulting in a serious load imbalance. Second, for air travelers, the choice of an access mode is secondary to and conditionned by the air leg of their trip. Third, airport access traffic has its own requirements, such as a peculiar time distribution, the need for baggage space, etc. Finally, the result of the estimation of the airport traffic will be highly contingent upon whether or not transborder and domestic flights are moved from Dorval to Mirabel in the future, and if so, when. This is not known today.

By progressive elimination, it appears that the inter-city traffic is the appropriate market target for a HSGT service between Montreal and Ottawa. The characteristics of that market segment will thus be analyzed to serve as a basis for the service strategy, as discussed in the next section.

However, the airport traffic should not be ignored altogether, as it could provide a useful contribution to covering the costs of the HSGT. As airport access trips are not made daily, air travelers would probably not be too susceptible to the relatively high fare of the HSGT: air travelers would not behave as commuters. Since airport access travel-making peaks do not coincide with those of inter-city travel, the attraction of air travelers would in all likelihood not affect the design capacity of the system, or overload it, but rather improve its load factor.

The HSGT service will then be designed for the Montreal - Ottawa inter-city traffic with a view to the airport-related traffic.

3.2 Functional Requirements of Intercity Traffic

There exist universal and specific functional requirements; these should be identified and considered prior to specifying performance for the Montreal - Mirabel - Ottawa HSGT. Universal requirements concern safety and comfort. Specific requirements correspond to characteristics of the market to be served.

As universal requirements, safety and comfort should be the same whatever the technology or the application. They can be represented by industry standards that are well documented in specialized publications. For safety and comfort, ISO standards will be used in this study, as explained in the next section.

The best source of information concerning specific requirements of the chosen target market is a study sponsored by TDC on the modal choice of intercity travelers between Montreal and Ottawa. A report on that study was published in 1976, covering the work done to that date; this report is summarized in Section A.2 Appendix A. The quote below summarizes the most significant findings.

"In response to a question asking them to list the three most important attributes used in their selection of the mode of transport for the trip, travelers of all modes, both business and pleasure, listed "convenience of schedule", "door-to-door travel time", and "safety" most prominently. Business travelers on air and rail also listed "being confident of arriving on time"; on bus, "minimum of advance arrangements" was listed; and on car "convenience of auto at destination" was listed as frequently as the above three attributes" (1, p.84). Pleasure travelers on bus, train, and car listed "total costs" as frequently as the three basic attributes; when on air, they also listed " being confident of arriving on time".

The above paragraph provides a good summary of the functional requirements of the Montreal - Ottawa intercity travelers. The system performance will be based on those requirements.

From the information available on air travelers that could use the HSGT as an airport access mode, it does not appear that they have any specific requirements that differ dramatically from those of intercity travelers. The requirement of having a car at the destination does not apply to their access trip, and they might be somewhat more sensitive to price than intercity business travelers.

3.3 Performance Specification

The performance specified for the Montreal - Mirabel - Ottawa HSGT service is summarized in Table 3-1 and explained below.

3.3.1 Geographic Coverage

The Montreal terminal should preferably be located in Central Station, as it is VIA's policy to concentrate its activities in a single terminal in every city that it serves. In Montreal, VIA uses Central Station. In Ottawa, the terminal should be at the existing VIA station, as it is relativelly well located. A downtown location might be preferable, but its feasibility would have to be demonstrated, which is well beyond the scope of the present study.

One intermediate station is given by the terms of reference for the study: Mirabel Airport. That station should be located under the existing terminal building, which has been designed to accomodate a transit system in its lower level. Near that station, the alignment should be such that a stop at a future terminal building is possible; in time, a second stop in Mirabel may or may not, in fact, be judged desirable.

No intermediate station should be planned for the Ottawa suburbs, as it is not justified by the area or population of the city.

In Montreal, the situation is different, as explained in Section 1.4. A suburban station appears even more advantageous if the airport-related traffic is taken into account.

3.3.2 Level of Service

The major parameters of the level of service are travel time, average speed, operating schedule, frequency, and delays.

The average speed can be measured by the terminal-to-terminal travel time. In this case, a trip from Montreal to Ottawa with a station stop in Mirabel should not last more than 75 minutes. This is consistent with the VIA Corridor planning and ensures the minimum time margin over automobile travel that will entice drivers to leave their automobile at home and use the HSGT. An even higher average speed would be a definite improvement.

The operating schedule should be such that it covers fully the peaks of inter-city travel, which are dictated by the "9 to 5" workday, while ensuring a good connection with international flights that leave Mirabel daily, from 20 to 22h. A schedule such that there are departures during fifteen or sixteen hours per day would meet these objectives, this amounts to a period of operation in the order of 16 to 18 hours per day.

The frecuency of departures should be high, to provide a valid competition to automobile travel. Considering a greater density of departures early in the morning, around lunch time, in the late afternoon, and early evening, it appears that fifteen departures per day is satisfactory. Departures might be at 45 minute intervals in peak periods, at 2 h off-peak.

3.3.3 Safety

Safety is of prime importance. Every precaution must be taken to ensure a very high degree of safety.

Table 3-1

Performance and service Specification

Subject Area	Parameter	Specification
Geographic Coverage	Terminal Location	Montreal: Central Station Ottawa : VIA Station
	Intermediate Stations and their location	Mirabel : Unver terminal building Ottawa : none Montreal: possibly a suburban station, easily accessible from the West Island
Quality of Service	Travel Time	Terminal-to-Terminal travel time not to exceed 75 minutes
	Operating Schedule	15 hours/day 7 days/week
	Frequency	1 departure/h on the average; higher frequency in peak periods
	Delays	No delays on line due to operational constraints
Safety	Collision Protection	Automatic anti-collision Automatic anti-overspeed Automatic route protection No grade crossings Emergency braking rate: 4 m/s^2 max.
	Train Operation	Continuous speed control
	Train Supervision	Automatic train location Two-way communication with central Centrally - controlled P.A. System
Ride Comfort	Lateral Acceleration	1 m/s^2 maximum
	Vertical Acceleration	1 m/s^2 maximum
	Jerk	0,5 m/s^3 maximum
	Vibrations	ISO reduced comfort Boundary for a 75-minute trip

The various types of collisions must be prevented. To that end, there should be automatic fail-safe systems for the following functions: anti-collision, anti-overspeed, switch positioning, and route interlocking. All grade crossings should be eliminated, by one of the three following strategies: construction of grade-separation structures, installation of truly safe crossing protection equipment (yet to be developed), or closing-off of the cross road. For safety inside the vehicle, the emergency braking rate should be such that passengers are not thrown off their seat when brakes are applied in an emergency.

There should also be a continuous speed control. To minimize human errors, all trains should furthermore be operated automatically, with no manual override capability except under precise controlled conditions.

For central supervision, trains should be automatically identified and located. In addition to the normal two-way communication between vehicles and central control, there should also be a public address system in vehicles and stations; it also should be centrally-controlled.

3.3.4 Ride Comfort

Ride comfort is an important element of level of service, as outlined by traveler surveys and discussed in Section A.2.

The lateral and vertical accelerations should be limited to 1,0 m/s^2, the jerk to 0,5 m/s^3. Vibrations should be limited according to an ISO standard: the reduced comfort boundary level for a 75-minute trip.

Reference for Chapter 3

1. Transportation Development Agency, "Mode Choice for Intercity Passenger Travel Montreal-Ottawa: A Working Paper", Report TP 234, Transport Canada, Ottawa, 1979.

This page left blank intentionally.

4. ROUTE SELECTION

Route selection is based on the location of terminals and intermediate stations that must be served by the system under consideration, on the geographic, topographic, geological and land use features of the terrain between these points, as well as on any constraints and/or advantages related to the technology of the system.

This chapter reports on the process of selecting a route for each of the two HSGT technologies being compared in this study. The principles for the selection are discussed in the first section of the chapter and constraints that must be taken into consideration, in the second.

The process of selecting an alignment for Maglev is discussed in the third section; the chosen alignment is described in the fourth section. The process of selecting an alignment for Rail is discussed in the fifth section; the chosen alignment is described in the sixth and last section. Complementary information and the plans and profiles of the chosen alignments will be found in Appendices C and D, respectively.

In this study, the selection of a route is necessary to obtain a realistic basis for cost estimation. With this in mind, every effort has been made to select a route that presents constraints and/or advantages that are truly representative of those that would be found on the "best" route between Montreal and Ottawa via Mirabel.

As this is not a planning study, however, no claim is made to the effect that the routes selected are optimal with respect to their service attractiveness, their engineering difficulties and/or their environmental and other impacts. To arrive at such a conclusion would require analyses that are clearly beyond the scope of the present study.

4.1 Principles for Route Selection

When selecting an alignment for a HSGT system in this study, the following principles were considered:

- terminals and stations should be located so as to best serve the potential traffic and to permit a convenient interface with existing access modes;
- the alignment must provide the most direct link between terminals compatible with the various service and terrain constraints and system parameters;
- the alignment chosen must allow each technology to travel at its maximum speed on the greatest proportion of the route;
- transition curves and other easements must be introduced in the alignment, so that maximum speed can be maintained without sacrificing passenger comfort;
- the alignment must permit the lowest possible construction cost given its geometric constraints;
- the alignment should minimize adverse environmental impacts and avoid activity relocation and community disruption;
- to minimize construction and operating costs, the alignment should be implemented in existing rights-of-way wherever possible technically, financially, and institutionally, without unduly compromising the quality of service.

The application of these principles will be done for the levels of service and performance already specified in the preceding chapter. In addition, the alignment selected must reflect the service philosophy underlying VIA's Overall Concept Specification for the Corridor.

4.2 Constraints to Route Selection

There are two types of constraints to the selection of a route for a Montreal - Ottawa HSGT. Environmental constraints stem from the chosen policy of avoiding encroachment of residential areas. Geometric constraints differ between the two modes as a result of their difference in speed and technology.

4.2.1 Land Use Constraints

The policy decision to avoid house demolitions and/or relocation as well as community disruption in residential areas implies, practically, that only alignments on existing rights-of-way will be used for routes in urban areas.

This constraint is practically meaningless in and around Ottawa, as there is an existing railway right-of-way that is oriented in the appropriate direction and well-connected to the Ottawa Station. This right-of-way, consisting of the CP M.&O. Subdivision and the CN Ottawa Subdivision, also appears presently under-utilized. It is, then, the most logical route there, for both technologies.

The land use constraint has little impact around Mirabel also, as the area surrounding the air terminal is presently not urbanized. Furthermore, the policy adopted when building Mirabel stipulated that development around the airport would be severely controlled, so that future urbanization close to the HSGT station and/or right-of-way is not to be expected.

Land use constraints have the greatest impact on the Montreal Island. That impact is felt first in the selection of a site for a Montreal Terminal for the HSGT.

4.2.2 Location of the Montreal Terminal

When looking at possible sites for such a terminal, one is practically restricted, due to the land use constraints, to existing transportation terminals. Of these, only railway stations are close enough to existing rights-of-way that could possibly be used for access to and egress from the Central Business District (CBD). Thus, only Central Station and Windsor Station should be considered as possible sites for the HSGT terminal; both are easily accessible by the various urban transportation modes.

Between the two, from a geographic and operational viewpoint, Central Station offers a better prospect for a HSGT alignment, as the right-of-way that connects Central Station with the railway network from to the North (the Mount Royal Tunnel) offers the shortest distance between the Montreal CBD and Mirabel Airport.

Also, VIA's service policy is to have only one terminal in each city that it serves. In the case of Montreal, this terminal is at Central Station.

4.2.3 Location of the Mirabel Station

When the Terminal 1 building for Mirabel Airport was designed and built, space was provided at ground level for a future transit system, which, having its station directly under the main concourse, would provide a very high level of service for airport access (Figure 4-1).

In the present study, such a location was considered ideal for a station for a HSGT system providing an airport access service. It was thus assumed that the Airport HSGT station would be located there.

No detailed verification was undertaken on the site or with the institutions concerned, as previous work (1,2) indicates that there should be no major constraint to such an implementation.

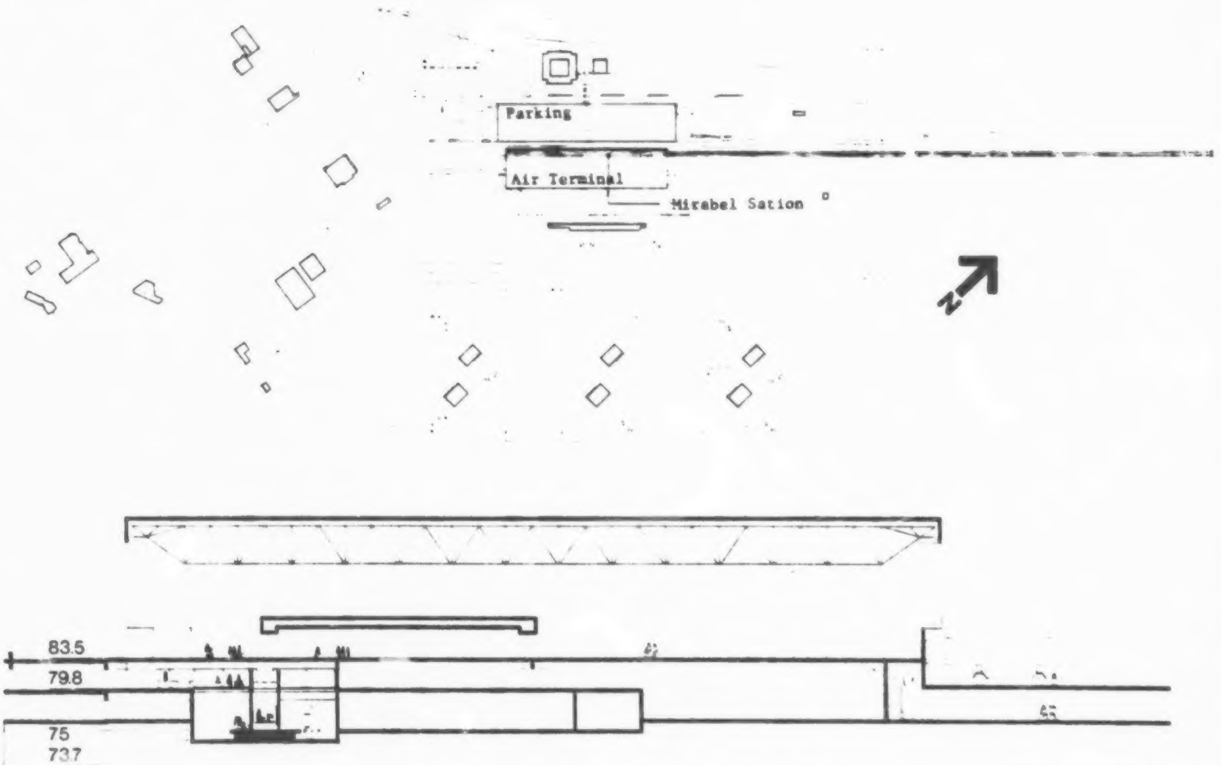

Parking
Air Terminal
Mirabel Sation
N
83.5
79.8
75
73.7

Figure 4-1 Location and Configuration of Mirabel Station

4.2.4 Technical Constraints for Maglev

In addition to the normal geometric constraints, three technical constraints are significant on the choice of an alignment for Maglev: the configuration of the standard Maglev guideway, the vehicle width, and the difficulty to share a railway right-of-way at grade.

After a number of studies, the optimal height for a Maglev guideway was found to be approximately 5 m, if the number of important cross streets is as usual in urban and suburban areas. A greater height would unduly increase the cost of columns and piers. A lower height would require a costly structure at each intersection (unless the cross street is closed). For a high density of cross streets, the total construction cost would thus be minimum for a 5 m high guideway, which requires no special structures at road intersections.

The width of a Maglev vehicle, as presently designed, is substantially greater than that of a standard railway car. That will impose constraints when the Maglev uses existing rights-of-way. These constraints will be felt when a railway right-of-way is restricted in width, as under existing structures. In the future, a narrower Maglev vehicle could be designed to remove that constraint. To obtain more reliable cost estimates in this study, it has been presumed that such a design, which would involve a significant rearrangement of the suspension and propulsion sub- systems, is not available by 1991.

As for Maglev sharing a right-of-way at grade with railway tracks, a guideway is in the process of being designed which could handle both a Maglev vehicle and a railway track. The use of that guideway would require the complete rebuilding of the railway track. But, more important, the switches that would allow the railway track, the Maglev guideway, or both simultaneously to merge into or diverge from the duo-mode guideway would be very complex. As they have not been designed yet, it will be presumed in this study that the duo-mode guideway is not available by 1991. Thus, a railway track and a Maglev guideway cannot share the same space in a right-of-way when both are at grade.

4.2.5 Technical Constraints for Rail

Although one would expect fewer constraints for Rail than for Maglev, as rail is a more mature technology, a high speed train, travelling consistently at 200 or 250 km/h, would have its own requirements. Some of these have already been outlined in Sections 2.2 and 2.3.

A high speed passenger rail service would require continuously-welded track, canted at a maximum of 6° superelevation in curves, and laid on a high-performance roadbed. This requires in fact complete construction of a new line, new double track, new ballast, new sub-ballast, new roadbed infrastructure in places. That high speed line will have to be equipped with high speed turnouts, all of them remotely controlled. The line will have to be maintained to very high standards.

Although these constraints affect primarily construction and operation, they also affect route selection in that an alignment on an existing railway right-of-way can only be considered if the necessary construction and maintenance operations can be performed effectively.

4.3 Selection of an Alignment for Maglev

This section will explain the rationale for selecting a route for Maglev between Montreal, Mirabel Airport, and Ottawa.

4.3.1 Montreal Terminal Location

Since Maglev cannot share tracks with other railway services under the Mount Royal, its route cannot use the existing tunnel. The cost of building a new tunnel approximately parallel to the existing one would be prohibitive. Furthermore, no right-of-way would be available at the exit of that new tunnel north of Mount Royal: it would be necessary either to extend the tunnel to Laval (even more prohibitive) or to create a new right-of-way through the Town of Mount Royal and north of it (unfeasible due to land use constraints).

If the Maglev used Central Station, it would have to follow CN Subdivision Montreal to reach the Lakeshore. That route, however, is very circuitous, crosses the Lachine Canal twice and includes several reversed curves resulting in speed restrictions that could not be lifted except at great expense if at that. It thus appears that Windsor Station is a better choice for a Maglev terminal. Access to the Montreal CBD would be along CP Subdivision Westmount.

It should be stressed, however, that the use of Windsor Station requires the construction of a good pedestrian connection between Windsor and Central Stations. Although it is possible today to walk underground from Windsor Station to Central Station, the route is circuitous and much too long and crowded for baggage-carrying travelers to walk comfortably.

4.3.2 Access/Egress to/from Windsor Station

After leaving the City Centre, the Maglev route must follow CP Subdivisions Westmount and Vaudreuil until it can turn toward Mirabel.

The first real opportunity is at the intersection of Autoroute 13, as no other right-of-way can be found east of it that could cross all of Montreal Island without substantial demolitions.

It does not appear possible, however, for the Maglev to turn at Autoroute 13 and follow it from its intersection with CP Subdivision Vaudreuil. First, the existing connection between Autoroutes 20 and 13, which passes under both the CN and CP rights-of-way, is complex and could not easily be rebuilt. Second, north and west of that intersection, Autoroute 13 is bordered by major railway properties, so that a Maglev guideway would have to be in the middle of the expressway. But the most severe constraint occurs where Autoroute 13 passes at the very end of Dorval Airport's prime runway, in a tunnel where there is no space for a Maglev guideway. The guideway could not be built over the tunnel either, because it would then interfere with the runway. So the Maglev guideway would have to be built in its own tunnel, either besides (to the east) or under the existing tunnel, both prohibitively expensive.

Instead, an alignment further West, using the Dorval Airport property wherever possible, will be used. In fact, the only route that would not require a very long tunnel under the runways is a route west of Dorval Airport. That raises the possibility of providing service to Dorval Airport, an issue discussed in the next sub-section.

4.3.3 Location of a Suburban Station

There could be several advantages to providing service to Dorval Airport. First, the Maglev could attract most if not all air travelers that must connect between Mirabel and Dorval. Second, the Maglev would attract originating and terminating air passengers that access Mirabel for an international flight: an important proportion of them reside in the West Island and would find a Dorval station convenient. Third, a suburban station located in that area would provide the system with an increased attractiveness to West Island residents using it for intercity travel from Montreal to Ottawa. Fourth and finally, a Maglev station in Dorval would facilitate connection between several other inter-city modes that have a station in Dorval: in addition to the air terminal, there is a rail station (it could still be used when the Maglev is implemented) and an intercity bus station. These could be linked together and with the Maglev Dorval Station with a shuttle service (3).

For this study, however, placing a Maglev station near Dorval Airport would tend to bias the technology comparison somewhat: Maglev would attract connecting air travelers not because of its technical advantages, but because of its alignment only, which is not technology-dependent but results from environmental concerns. For this reason, such a location for the suburban station will not be considered as part of the basic Maglev system in this study.

As the Maglev route will be near Autoroute 13 shortly before it crosses the Rivière des Prairies, the suburban station will rather be located approximately at the intersection of Boulevard Gouin and Autoroute 13. It should be noted that there are problems associated with finding, in that area, the large site required for a parking area commensurate in size with the importance of the station. This is due to the presence of a forest reserve and residential areas nearby. As this is a transportation planning issue, it will not be addressed further in this study.

4.3.4 Route through Laval

The preferred alignment would seem to be for the Maglev route to be inserted at grade in the median of Autoroute 13: no new structures would be needed, no expropriations necessary.

Unfortunately, a site survey revealed that the space in the median is insufficient for a double Maglev guideway. Building a single guideway might be sufficient for the first few years of operation only. Furthermore, the guideway would probably have to be built besides the expressway at toll plazas, as the Autoroute Authority would want to maintain the existing flexibility in the bi-directional use of toll lanes.

The site survey also showed that there is not sufficient space to build a single Maglev guideway at grade on each side of the Autoroute, such as between the express lanes and the service lanes. An elevated guideway could be built there, but, given the configuration of overpasses for cross roads, this guideway would have to pass either under or over the existing structures. To avoid a roller-coaster effect the guideway would have to be built level, at 10 m or more above ground: an expensive solution.

As a consequence, through Laval, the route selected consists of building a 5 m elevated guideway about 500 m west of Autoroute 13, as development is minimal on that side of the expressway. Such an alignment could involve, at most, the relocation of twenty houses, and would not cause significant environmental impacts as, for instance, the Maglev noise would probably not be perceived above that generated by Autoroute 13.

No special structures would need to be built to cross the Rivière des Prairies and the Rivière des Mille Iles, as the standard spans (up to 72 m) would provide enough clearance for pleasure craft and ice movement.

4.3.5 Station Location and Routing around Mirabel

The Maglev station at Mirabel Airport is located, like the Rail station, under the existing terminal building (Figure 4-1).

Between Mirabel and the end of Autoroute 13, there is substantial freedom for the selection of an alignment for the Maglev route, since much of the land is owned by Transport Canada and development is regulated.

4.3.6 Routing between Mirabel and Ottawa

From Mirabel towards Ottawa, the Maglev route will follow new alignment, which minimizes environmental impacts, until it crosses the Ottawa River around Hawkesbury. In Ontario, the Maglev route will coincide with the alignment selected in the Alternatives to Air Study (4). This alignment is well documented and was selected to minimize construction difficulties in soft terrain.

Access to and egress from Ottawa will be along Canadian Pacific's M.&O. Subdivision. The Maglev station will coincide with VIA's Ottawa Station.

A downtown location might be preferable. To determine its feasibility would require a considerable amount of analysis and planning. By its nature as well as by its importance, this work is well beyond the scope of the present study.

4.4 Description of the Maglev Route

The Maglev route is shown in plan on Figure 4-2.

Starting from its Montreal terminal in Windsor Station, the route selected follows the CP right-of-way (Subdivision Vaudreuil) towards Dorval through the suburban cities of Westmount, Montreal West, Saint-Pierre, Lachine and Dorval for a total distance of about 17,5 km. The Maglev guideway is built 9 m above rail, on a structure placed above the tracks on the north side of the right-of-way. This height allows clearance of the signal bridges; near Windsor Station the guideway is placed 15 m above rail to clear two highway overpasses.

In Dorval, the route veers sharply to the northwest and passes through a small neighborhood park; this entails demolition or relocation of four single-family houses, two 20-unit appartment houses, as well as a small elementary school. In that area, the guideway is at grade to minimize environmental impacts as well as to allow the required clearance as it passes near the end of Dorval Runways 06L and 10.

The route then turns northeast and climbs to 9 m again, to be aligned along CN Doney Spur through the Hymus Boulevard Industrial Park, then veers northwest to cross Autoroute 40. From then on, the guideway is generally built on an elevated structure, 5 m above the terrain. There is a Maglev station near the intersection of the route with CN Subdivision Montfort.

Through Laval, the Maglev route is generally built about 500 m west of Autoroute 13, as there is no remaining space for a double guideway on the expressway right-of-way (unless all existing structures are rebuilt). Few houses need to be relocated.

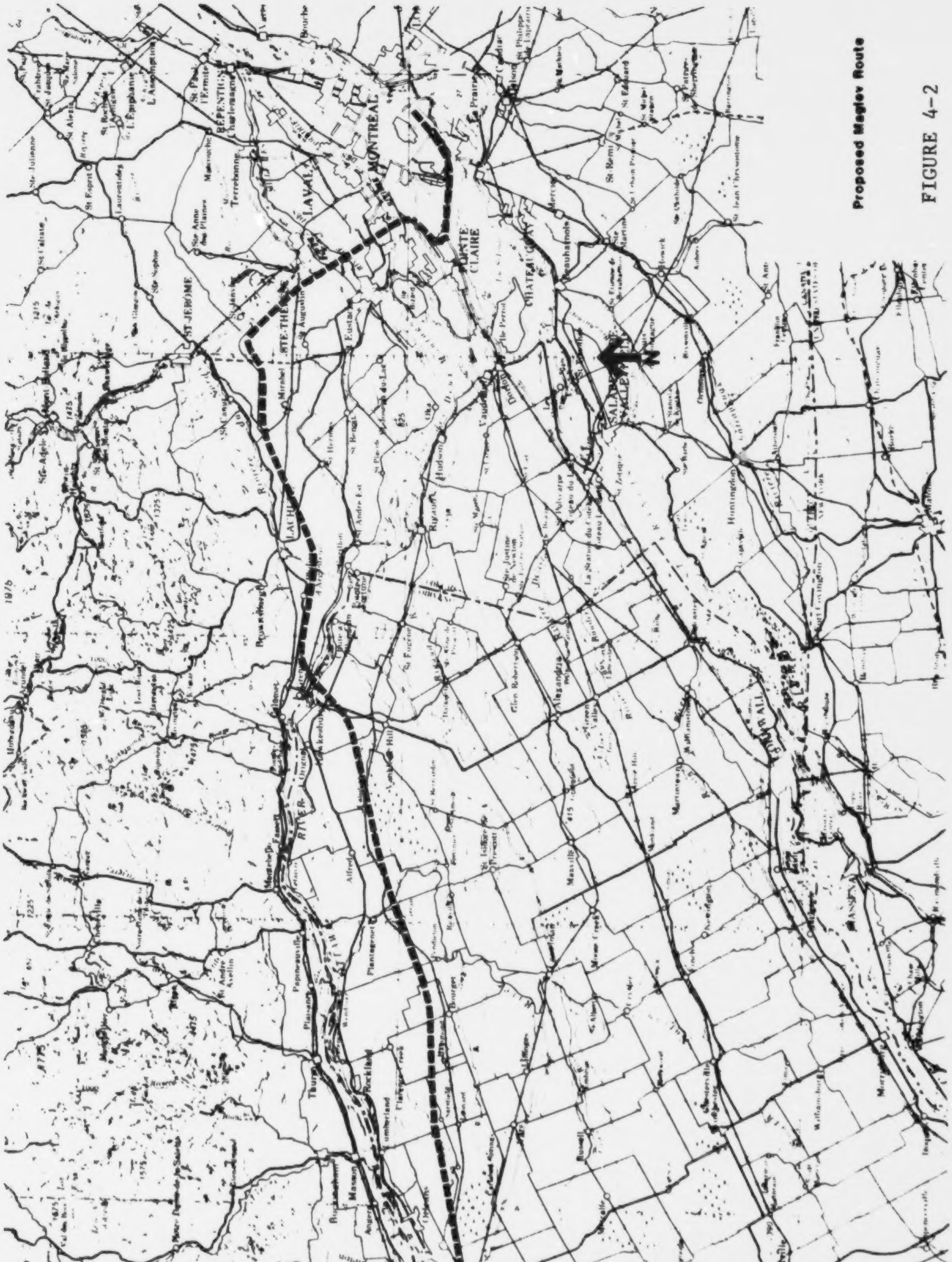
After crossing Rivière des Mille Iles with standard spans, the route follows a straight alignment about 500 m west of Autoroute 15, always built on a structure. Near St-Janvier, at km 50, the route turns towards Mirabel.

Near Mirabel Airport, the route descends to access the underground station in the terminal building. As it leaves the terminal, the route turns and climbs sharply to an elevated configuration, then follows an alignment parallel to the Spine Road.

From then on, the guideway is built 5 m above ground and the route follows an alignment defined in the "Alternatives to Air" Study (4) and selected to minimize construction difficulties in soft terrain. The route thus passes south of Lachute, south of Saint-Philippe d'Argenteuil, to cross the Ottawa River slightly east of Hawkesbury (Ontario) at km 102. From km 116 to km 130, the route passes north of the Alfred Bog, then it continues almost straight all the way to Ottawa. From km 180 on, the route is built right along CP Subdivision M.&O., which it has followed at some distance since km 120.

The guideway descends to ground level to pass under Highway 417 and St. Lawrence Boulevard; existing overpasses over the railway will be rebuilt. Light industries bordering the railway may have to be rebuilt.

Ottawa Station is reached at km 189+500.


MONTREAL
LAVAL
POINTE CLAIRE
CHATEAUGUAY
ST-JEROME
STE-THERESE
REPENTIGNY
SALABERRY
LACHUTE
Hawkesbury
Rockland
Thurso
Papineauville
Plantagenet
Alfred
Hudson
Rigaud
Alexandria
Huntingdon
Cornwall
HULL
Kemptville
Richmond
RIVER

Proposed Maglev Route

FIGURE 4-2

4.5 Selection of an Alignment for Rail

This section will explain the rationale for the selection of a route for the Rail technology between Montreal, Mirabel Airport, and Ottawa. The section is divided into four sub-sections: terminal location, access to the terminal, suburban station, Mirabel Station location.

4.5.1 Montreal Terminal Location

For reasons discussed in sub-section 4.2.2, Central Station will be considered as the Rail terminal in this study.

4.5.2 Access/Egress to/from Central Station

The shortest route to reach Mirabel from Central Station is to use the existing Canadian National tunnel under Mount Royal.* This also happens to be one of VIA's preferred routes for Montreal - Ottawa service in its Corridor planning: it is the alignment recommended for the intermediate and high speed rail alternatives.

Routing the Rail system through this tunnel is possible, but requires sharing tracks with other railway services: VIA's daily services to Quebec and Toronto (which would use the tunnel in 1991), as well as the existing Deux-Montagnes commuter service or, possibly, future improved commuter service now being planned.

Despite this constraint, the tunnel has been adopted for the Rail route for comparison purposes; the time and other penalties associated with using the tunnel and sharing the tracks will be evaluated later in the study. Existing tracks would have to be rebuilt entirely.

---

* In Montreal, this tunnel is often described as heading North, but in fact it heads almost due West.

As it exits the tunnel, the Rail route will continue on CN Subdivision Mount Royal, on its own exclusive tracks, passing through the Town of Mount Royal in an existing cut.

The Rail route will follow the existing railway right-of-way through the western part of Montreal Island, across the Laval islands and Ile Jésus (Ville de Laval), and onto the mainland up to the railway junction in the area known as La Fresnière.

4.5.3 Location of a Suburban Station

To avoid biasing the comparison, the suburban rail station will be located near the intersection of Autoroute 13 and CN Subdivision Montfort. This will be very close to the proposed Maglev suburban station and will thus entail the same insertion difficulties; these were mentioned in Sub-section 4.3.3.

4.5.4 Station Location and Routing Around Mirabel

The station at Mirabel Airport will be located in the lower part of the Air Terminal building.

The route must connect the railway junction at La Fresnière with the Mirabel Station. The easiest way to do that is to align the route almost directly between these two points; it will thus pass between the two groups of existing runways in a tunnel. This choice of this alignment will introduce a switchback at Mirabel; the operational implications of that switchback are discussed in Chapter 5.

From Mirabel to Ottawa, the Rail route will first follow the Spine Road, then follow a new alignment that minimizes environmental impacts, before joining Grenville Spur of CN Subdivision Montfort then leaving it for a new right-of-way. After crossing the Ottawa River around Pointe Fortune, the route joins CP Subdivision M.&O., which it follows to Ottawa.

4.6 Description of the Rail Route

The Rail route is shown in plan on Figure 4-3.

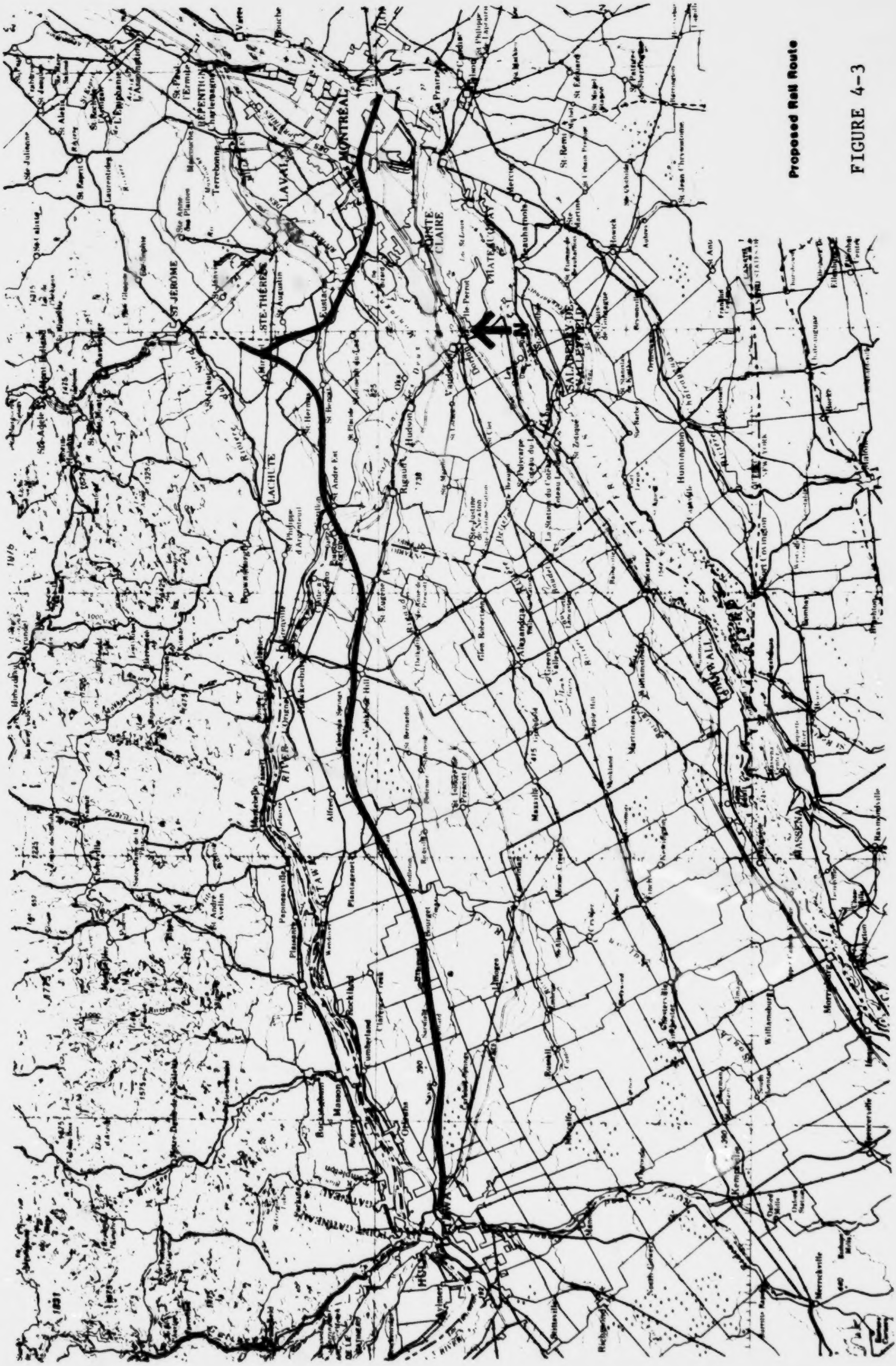
Starting from its Montreal terminal at Central Station, the route selected follows CP Subdivision Mount Royal through the tunnel under Mount Royal: in the tunnel, the two existing tracks will be rebuilt and shared by commuter trains and inter-city trains.

As the route exits the tunnel, the Rail system will have its two exclusive tracks built on the west side of the right-of-way, with two exclusive commuter tracks on the east side. Where needed, industrial service tracks will be built outside these four passenger tracks.

The Rail route will remain in the CN right-of-way all the way to Deux-Montagnes, always on the west side of the commuter tracks. Most structures in this route section will have to be rebuilt to accomodate five and, exceptionally six tracks. The suburban station will be located near the crossing of Autoroute 13.

North of Rivière des Mille-Iles (except for 3,5 km at La Fresnière) the route remains in CN Subdivision Montfort for 12 km, then leaves it to enter Mirabel Airport on a new alignment, around 45 km from Montreal.

The proposed Rail route is aligned between the existing runways. The tracks will be built in a cut to clear all landing paths of existing runways and pass under future runways. A 1,7-km tunnel will be built where the alignment passes under existing taxiways, airport service roads, and buildings. When in an open cut, the alignment may have to be covered to prevent radio and radar interference.


MONTREAL
LAVAL
STE-THERESE
ST JEROME
LACHUTE
POINTE CLAIRE
CHATEAUGUAY
SALABERRY-DE-VALLEYFIELD
Hudson
Rigaud
Alexandria
Huntingdon
CORNWALL
MASSENA
OTTAWA RIVER
Hawkesbury
Rockland
Plantagenet
Papineauville
Masson
Buckingham
GATINEAU
HULL
Aylmer
Kemptville
Morrisburg
Winchester
Prescott
St Eugene
Vankleek Hill
Alfred
Embrun
Bourget
Osgoode

Proposed Rail Route

FIGURE 4-3

The Mirabel Airport Station will be located at km 50 under the air terminal building, which has been designed in preparation for such a development. After serving the station, all trains will reverse direction and follow the alignment used in entering the airport.

Five kilometers after leaving the Airport Station, the route branches towards Ottawa. When reaching that point, the train has travelled 55 km since leaving Central Station.

The route then proceeds towards the Ottawa River which is reached near Saint-André. Between there and Mirabel, the route is generally built on a new alignment designed for high speeds, and follows CN Grenville Spur brieffly. After crossing the river, the route reaches the right shore at Pointe-Fortune, then enters Ontario, and, 13 km later, joins CP Subdivision M.&O., near its crossing with Highway 417 in the Vankleek Hill Area.

From that point toward Ottawa, the Rail route generally coincides with CP Subdivision M.&O. There is an exception around Plantagenet where the alignment follows a more direct route designed for high speeds, for approximately 12,5 km.

The passenger tracks are built on the south side of the right-of-way; thirty-five km from Ottawa, they move to the north side to avoid numerous existing sidings on the south side.

Ottawa Station is reached at the end of a 185 km route. Due to the switchback at Mirabel, the train has actually travelled 190 km.

References for Chapter 4

1. GENEST, Bernard-André et al., "Report on the Feasibility of a Mirabel-Montreal Airport and Regional Transit System", Ministère des Transports du Québec, Montréal, 1974.

2. Bureau d'aménagement du réseau express de Montréal, "Réseau express de Montréal: Ligne Mirabel" Ministère des Transports du Québec, Montréal.

3. Econosult Inc., "Etude de faisabilité d'un service de navette à Dorval" pour le Centre de Développement des Transports, Transports Canada, Montréal, 1982.

4. Canadian Institute of Guided Ground Transport, "Alternatives to Air: A feasible Concept for the Toronto-Ottawa-Montreal Corridor", for Report TP 2667, for Transportation Development Centre, Montreal, 1980.

This page left blank intentionnally.

5. RAIL SYSTEM DEFINITION AND COSTS

The objective of this chapter is to identify, describe, dimension, and enumerate all the components making up the Rail system used for comparison in this study, and to present an estimation of their costs.

The first section in this chapter presents the principles and assumptions used for defining the system; they are the same for both technologies. These principles and assumptions are based on the traffic forecasts (Chapter 1) and performance specifications (Chapter 3) outlined previously. The second section in the chapter describes the method used for system definition, as well as the design conditions on which that definition is based and the principles and methods used for cost estimation.

The third section discusses the operational strategies used as a basis to define the required system capacity and adapt it over the years to the expected growth of traffic. The fourth section outlines the technical characteristics of the vehicle and explains how the size of the fleet required for operation was evaluated. The fifth section describes the infrastructure for the Rail system: right-of-way, track, track foundation and structure, track equipment, etc.

The sixth section covers the structures, the seventh, the stations, while the eighth discusses the equipment necessary for the following system functions: power supply, power distribution, command and control, communications, maintenance. The ninth section outlines the operating procedures used a basis for estimating the personnel requirements and corresponding salary costs; the tenth section does the same for maintenance. The eleventh covers energy costs.

Many of these sections are complemented by a corresponding section in Appendix E, where detailed documentation will be found on most system components.

5.1 Basic Assumptions Underlying System Definition

The comparative technology assessment being performed in the present study must above all identify the fundamental differences between the Rail and Maglev technologies.

To facilitate their identification, it was felt useful to resort to the concept of a "basic system", under the assumption that comparing two "basic" systems with a minimum of contextual differences should underline the essential technological differences. After the basic systems are defined and compared, each system can eventually be optimized so that its revised definition reflects its specific advantages and the precise requirements of the application.

To maintain a greater degree of objectivity, the same assumptions were used in defining the basic system for both technologies; this common basis and the use of similar definition procedures also helped avoid overdesign or underdesign in any of the two basic systems. Most of these fundamental assumptions are a direct reflection of the Performance Specification (Chapter 3).

5.1.1 Geographic Coverage

Both systems will provide high speed service between the city centers of Ottawa and Montreal through Mirabel Airport. In Montreal, both systems will have their terminal in the very core of downtown, and a suburban station in the West Island; to avoid differential effects on ridership, this station will be very nearly in the same location for both systems. Both systems will have their Mirabel Station on the ground floor of the existing terminal building, as well as their Ottawa terminal at the existing VIA Station.

5.1.2 Routing

All trains will go from Montreal to Ottawa (or vice-versa) with two mandatory station stops: one in Mirabel and one at their suburban station. No train will provide service beyond Montreal or Ottawa or skip the Mirabel Station or the suburban station. The actual route alignment is as described in Chapter 4.

5.1.3 Time Coverage

Service will be provided seven days a week, fifty-two weeks a year. The schedule will be such that in the evening, the last train will leave each terminal approximately 18 hours after the first morning departure.

5.1.4 Frequency of Service

The frequency of service will be dictated by service considerations, not by capacity requirements. The frequency will be such that there is, on a daily average, one departure per hour from each terminal. Departures will be more frequent early in the morning, around lunch time, at the end of the normal business day, and early in the evening for flight departures from Mirabel.

5.1.5 Capacity

Given a frequency fixed by service considerations, capacity will be changed by varying train length: train length will be such that the required capacity is offered, yet a realistic load factor is obtained. A realistic load factor might be 90% at peak hours and 30% off peak, with a daily average in the order of 55%.

5.1.6 Safety

Safety standards outlined in Table 3-1 imply automatic train protection and the elimination of any grade crossings.

5.2 Methodology for System Definition and Cost Estimation

5.2.1 Sub-system and Geographic Disaggregation

For definition and estimation purposes, the basic system will be disaggregated along the following functional or physical sub-systems:

- capacity: schedules and train length (Sections 5.3 and E.1);
- vehicles (Sections 5.4 and E.2);
- infrastructure, including:
  - track layout (Sub-sections 5.5.1 and E.3.1);
  - right-of-way acquisition (Sub-section 5.5.2);
  - track materials (Sub-section 5.5.3);
  - track structure (Sub-sections 5.5.4 and E.3.3);
  - track construction (Sub-section 5.5.5);
- structures, bridges and tunnels (Sections 5.6, E.4, E.5);
- stations (Sections 5.7 and E.6);
- power and control equipment, including:
  - power supply (Sub-section 5.8.1 and Section E.7);
  - power distribution (Sub-section 5.8.2 and Section E.8);
  - command and control (Sub-section 5.8.3 and Section E.9);
  - communications (Sub-section 5.8.4.);
  - maintenance equipment and building (Sub-section 5.8.5);
- operational requirements and costs (Section 5.9);
- maintenance requirements and costs (Section 5.10);
- power costs (Section 5.11).

Whenever convenient, the sub-systems defined were further disaggregated according to location, as follows: Montreal downtown, Montreal Island, Laval, Mirabel, rural Ontario, Ottawa.

5.2.2 Design Conditions

The system design is based on conditions prevailing in the year 1991; specifically, its capacity corresponds to the median between the expected minimum and maximum traffic in that year as given in Table 1-14. After 1991, capacity expansion would be achieved through consist size adjustment.

The system is designed to handle traffic growth for 20 years after its service introduction in 1991. As an exponential decay of traffic growth is presumed from 2001 on, traffic growth would be null in the year 2011. If there was indeed some growth at that time, the necessary system expansions would be justified based on that growth; this was not considered in the present study.

5.2.3 Principles for Cost Estimation

The cost estimation is based on the system components required and work to be done, as described later in this chapter. It is limited by the level of detail to which the system definition could effectively be conducted in the framework of this study.

Unless otherwise noted, it is presumed that the work is done in Canada, by Canadian firms, according to Canadian business practices and principles, using conventional construction methods, and working under prevailing conditions and constraints regarding institutions, salaries and productivities.

In several cases, due to the innovative nature of the work envisioned and/or its sheer scope (by comparison with the present level of railway construction work in Canada), new construction methods would effectively be developed. These methods would (and, in fact, should, if they are to be implemented) result in construction cost savings; due to their speculative nature, these potential savings have been ignored, unless otherwise noted.

Construction cost estimates are based on the geographic subdivision of the project with simultaneous award of four major contracts, each allowing the contractor to hire sub-contractors for specialties.

It is presumed that the responsible authority will provide the contractors with institutional and physical access to the sites and with the surveying benchmarks necessary for accurately locating the alignment.

Whenever applicable, it is presumed that railway and automobile traffic are maintained throughout construction. The design and costs implications of this policy are discussed in some detail for structures (Section 5.6).

5.2.4 Cost Estimation Methodology

In general, construction costs were estimated based on unit costs observed recently on similar contracts. Such costs are normally public in Canada. Some institutions, such as Ministère des Transports du Québec, regularly publish disaggregated cost data on the contracts they awarded recently, with details on specific conditions. Such sources were used for calibrating unit costs for structures and for infrastructure (11).

Quantities were estimated as part of the definition of each subsystem. The results are presented in this chapter and details on the estimation of quantities are found in Appendix E.

5.3 Capacity Definition

To define the system capacity for this technology comparison requires a discussion of operational strategies: this discussion identifies what methods are presumed to be used for progressively adapting the system capacity to a growing traffic, while maintaining a satisfactory load factor.

Given an operational framework, the capacity of a rail service can be adapted to traffic by increasing the length of each train while maintaining the frequency constant, and/or by increasing the number of trains in peak and/or off-peak periods.

In this case, it was presumed that the frequency of service was maintained constant during the period of analysis, so that the necessary capacity increase was obtained by lengthening each train by the addition of extra cars. That way, the system infrastructure and fixed equipment maintain a capacity reserve that could conceivably be used for introducing additional trains, for a Montreal - Toronto service through Ottawa and Kingston, for instance. This approach also avoids introducing frequency-associated ridership bias in a technology comparison.

The corresponding evolution of capacity with time and traffic is shown in Figure 5-1. Details on its derivation are found in Section E.1.

Based on the assumed train performance (Section E.2), travel time is estimated to be 70 minutes, including 90 s stops at each of the two intermediate stations. This estimation of travel time takes into account speed restrictions through curves corresponding to a maximum lateral acceleration of $0{,}7\ m/s^2$, which is the comfort limit with a 6° superelevation (the maximum for Rail).

The resulting train traffic pattern, illustrated in Figure 5-2, will apply from 1991 to 2011. This diagram shows that six trainsets are required in operation to provide the service.

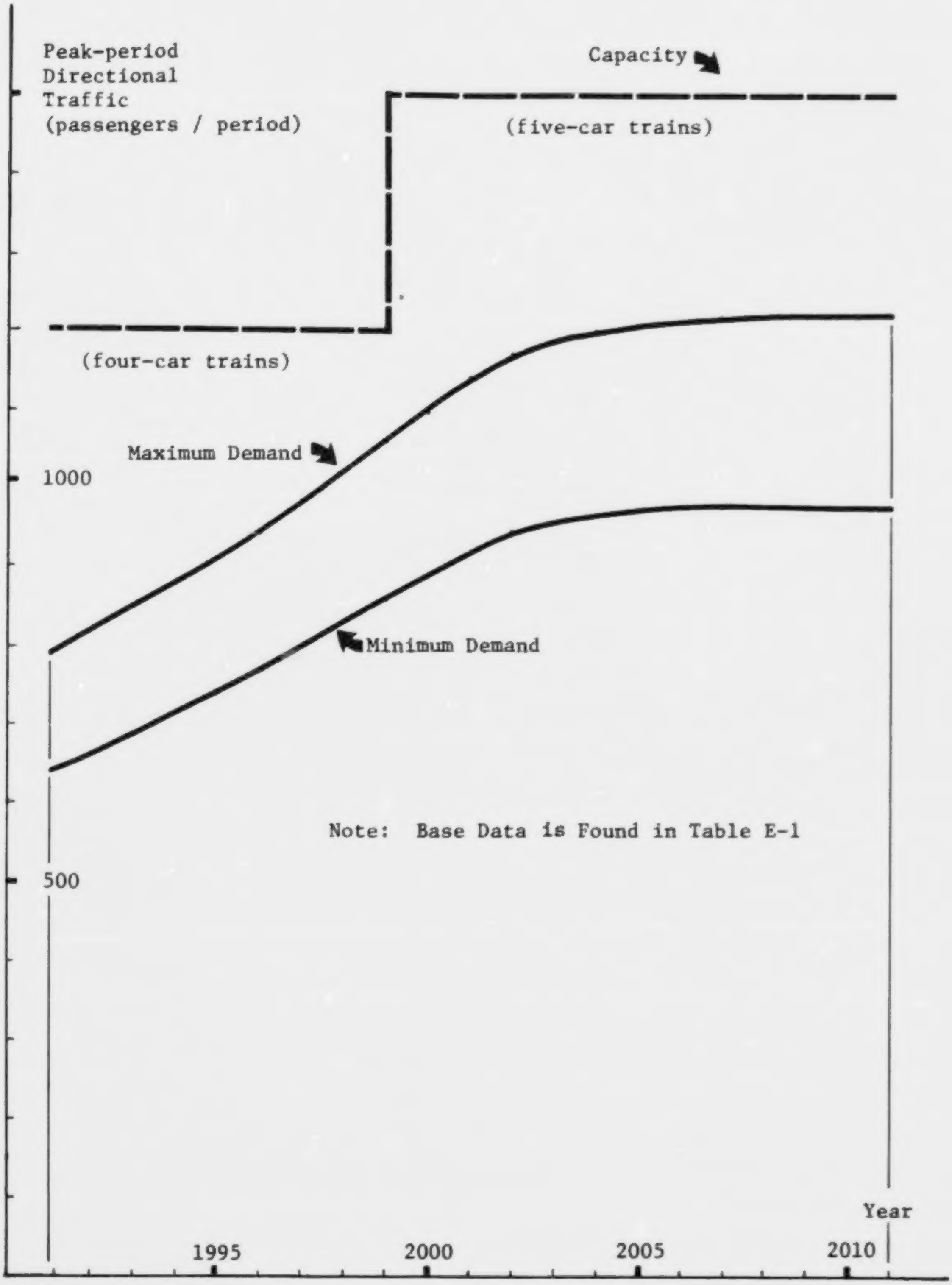


Figure 5-1 Traffic Growth and Capacity Adjustement for Rail

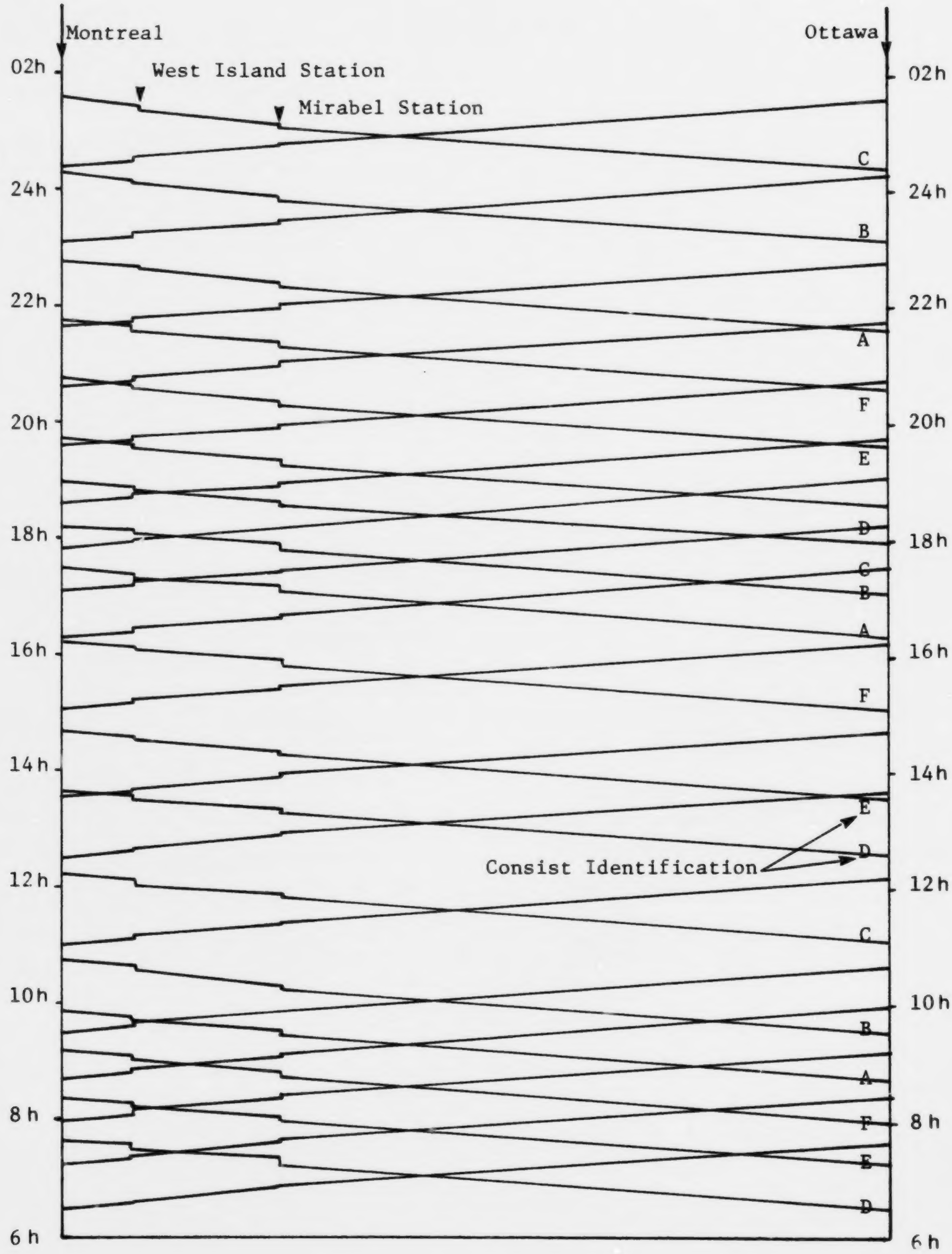


Figure 5-2 Train Traffic Pattern For Rail

5.4 Vehicles

Vehicles considered for the Montreal - Mirabel - Ottawa application must respect the following operational criteria, which are consistent with the performance outlined in the preceding section and detailed in Section E.2:

- multiple unit configuration;
- push-pull operation;
- electrical propulsion;
- standard North American dimensions (3,2 m width, 25,9 m length);
- capacity: 75 passengers per vehicle;
- maximum operating speed: 200 km/h;
- axle loads: 190 to 210 kN maximum at 200 km/h.

No Canadian rail vehicle presently meets those requirements, although Canadian manufacturers could build this type of equipment under licence or, eventually, from their own design.

As no specific design is contemplated, the cost of rolling stock was estimated by analogy with existing designs; the cost of the four- car self-propelled unit envisioned was thus approximated by considering a conventional locomotive-hauled four-coach train. The resulting estimate was compared to the actual cost of existing foreing designs for self-propelled units of the same type and capacity.

As the passenger comfort sought is comparable to that offered by LRC coaches, the mechanical cost of the four-car unit was presumed equal to that of four LRC coaches. Based on recent sales to VIA Rail, the current unit price of an LRC coach can be estimated at $1,6 M for an order for 36. Consequently, the cost of the mechanical portion of the four-car self-propelled train would be $6,4 M.

To obtain the required performance while pulling four LRC coaches, a 6000 kW electric locomotive could be used. The cost of such a locomotive is thus a reasonable indication of what the cost of the electrical equipment for the four-car self-propelled train would be. According to trade sources, the unit cost of a 6000 kW, 25 kV locomotive would be in the order of $3,5 M for an order for 9 units.

Combining the mechanical and electrical components, the cost of a self-propelled 25 kV four-car unit would amount to $9,9 M, say $10,0 M, for an average cost per car of $2,5 M. The cost of additional cars to be purchased for 1999 would also be $2,5 M each (in 1983 dollars). Thus the cost of $10,0 M per train represents a reasonable indication of what would be today's cost for a four-car electrical multiple unit operating off a 25 kV single-phase 60 Hz power supply and offering the required performance (described in Section E.2).

This estimate presumes that the train is Canadian-built, based on existing Canadian technology, such as LRC, and developed progressively using technical assistance and expertise, as well as some hardware components, from foreign countries that have experience with such designs.

From available information on current prices, off-the-shelf purchase of foreign rolling stock would probably be less expensive as far as capital expenditures are concerned. But foreign equipment might not be adapted to Canadian railway operating practices, and would offer little by way of manufacturing impacts, research and development potential, or technology spin-offs. The differential can be considered the assumed cast of "Canadianization"

Based on the performance envisioned and an assumed turnaround time of 40 minutes at terminals, six trains will be needed for operation, as shown in Figure 5-2. In addition one train is assumed to be kept in standby at each terminal, as an operational reserve, ready to leave in case a train used for operation becomes disabled.

Each train would be sent periodically to the shop for preventative maintenance, as a unit. Based on experience with the HST (diesel) in the U.K. (8) and the TGV (electric) in France (9,10), each train is expected to be taken out of service for scheduled maintenance for a total of 25 days per year: it will thus be unavailable around 7% of the time. Accordingly, the fleet should include a ninth train, providing an 11% reserve for maintenance, slightly in excess of actual requirements.

The total fleet requirement for the Rail system is thus established at nine trainsets. Upon service opening in 1991, each train will consist of four cars and offer 300 seats. In 1999, a fifth car would be added to each train.

The total procurement cost for the nine four-car trains to be placed in service in 1991 is thus $94,5 M (CDN $ 1983), which includes a 5% provision for spare parts. Another capital expenditure of $23,6 M must be incurred in 1998 for additional cars to be placed in service in 1999.

5.5 Infrastructure

This section describes the following components of the Rail system:

- track layout, which results from operational strategies;
- right-of-way requirements, which result from the track layout;
- track components: rail, ties, and fasteners;
- track structure design;
- track construction;
- turnouts.

5.5.1 Track Layout

The Rail system will be operated on double track all the way from Montreal to Ottawa. The new track must be built on a new roadbed. In the Mount Royal tunnel only, this new double track will be shared with commuter trains; elsewhere, it will be used exclusively by the HSGT service.

To permit train movement on the opposite track when one track is disabled, double crossovers will be installed at the following kilometric points: 5, 16, 30, 44, 73, 96, 118, 140, 162, 184.

From km 5,4 to km 31,1, as the two new high speed tracks are being built, space will be reserved for two other new tracks for the exclusive use of future commuter services. Provision will be made for connection with those tracks, which could be built at the same time as the Rail tracks, but at the expense of the authority responsible for the commuter services.

To restore the present Canadian National track layout, a new freight track will be built on the south side of right-of-way, from km 8,6 to km 31,1 and another one on the north side, from km 11,3 to km 11,9.

The corresponding track schematic is shown in summary form in Figure 5-3.

5.5.2 Right-of-Way Requirements, Acquisition, and Rental

The Rail route, described in Section 4.6, follows existing railway rights-of-way wherever possible, so as to avoid environmental impacts and to minimize land acquisition.

The right-of-way requirements of that route are shown in Table 5-1: the system requires 410 ha of land, 171 ha on railways and 239 ha on private land. New right-of-way acquired from private owners will generally be 30 m wide. Exceptionnally, as in deep cuts or on high embankments, the new right-of-way will be 50 m wide.

Most land to be acquired is in rural areas. Based on information on recent comparable sales, it appears that a market value of $2 000/ha is representative of the price of agricultural land along the route: this amounts to $0.02/s.f. (square foot). Presuming that land can effectively be obtained at current market value, the acquisition of 239,08 ha should cost $0,48 M.

A small amount of urban land must also be acquired (0,25 ha), near Autoroute 13, for widening the right-of-way over a short distance. Based on recent sales in the area, industrial land near the CN right-of-way would sell for $0.50/s.f., that is $53 800/ha. The required acquisition should cost $40 400.

Land acquision from private owners should then cost $2,5 M in total.

Along the proposed route, 21 houses must be acquired and demolished or relocated. At current market values, this should cost $2,1 M ($100 000 per house on the average).

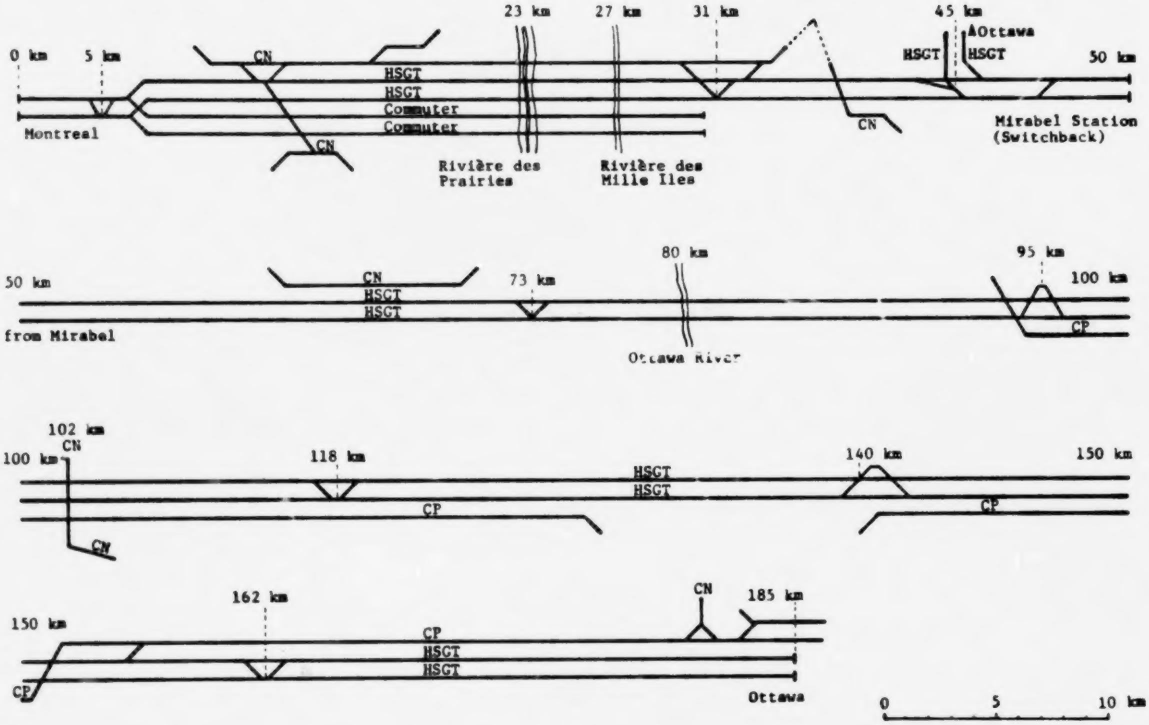

0 km
5 km
Montreal
CN
HSGT
HSGT
Commuter
Commuter
CN
23 km
27 km
31 km
Rivière des Prairies
Rivière des Mille Iles
CN
45 km
Ottawa
HSGT
HSGT
50 km
Mirabel Station (Switchback)
50 km
from Mirabel
CN
HSGT
HSGT
73 km
80 km
Ottawa River
95 km
100 km
CP
102 km
CN
100 km
CN
118 km
CP
HSGT
HSGT
140 km
150 km
CP
150 km
CP
162 km
CP
HSGT
HSGT
CN
185 km
Ottawa
0
5
10 km

Figure 5-3 Summary Track Schematic for Rail

Table 5-1

Right-of-Way Requirements for the Rail Route

Acquisition Policy and Present Status	Further Classification	Context	System Requirements		
			Width (m)	Length (km)	Area (ha)
Rental of Railway Rights-of-Way	By Location	Urban	15	41,06	61,59
		Rural	15	73,00	109,50
		Total	-	114,06	171,09
	By Present Ownership	CN-owned	15	38,16	57,24
		CP-owned	15	75,90	113,85
		Total	-	114,06	171,09
Outright Expropriation of Land in Private Ownership	By Location and Width	Urban	15	0,50	0,25
		Rural	15	12,00	18,00
		Rural	30	49,90	149,70
		Rural	50	14,28	71,38
		Total	-	76,68	239,33
	By Present Land Use	Woodland	Variable	21,30	65,60
		Farm/Undeveloped	Variable	55,38	173,73
		Total	-	76,68	239,33
All	Any	Any	-	190,74	410,42

The route follows existing rail rights-of-way for 114,06 km. It will be presumed that the Railways are not prepared to sell their land, but are willing to accept long-term leasing of some portion of it.

A strip of land 15 m wide is required for the Rail system; physically, that space should be available, as rights-of-way under consideration, nearly everywhere, are 30 m wide and are occupied by a single track only. It will be presumed that this land can be leased at an annual rental equal to 10% of its value. There are precedents for such an arrangement, on the Northeast line of the Edmonton LRT, for instance.

The value of industrial land near the CN right-of-way in Montreal Island and in Laval can be approximated by the following formula:

$$P_r = P_o e^{-br}$$

P_r: value of land at r km from the city centre
P_o: value of land at the city centre ($150/s.f.)
b: an empirical decay factor obtained from an analysis of recent sales (b = 0,356)

This formula yields the following land values:

Distance from Montreal CBD	Land Value
0 km	$150.00/s.f.
5 km	$ 25.23/s.f.
10 km	$ 4.24/s.f.
15 km	$ 0.50/s.f.
20 km	$ 0.12/s.f.
25 km	$ 0.02/s.f.

Based on these numbers, the value of the and in the Mount Royal tunnel would be $32,9 M for a length of 5 km and a width of 8 m. The corresponding annual rental would be $3,3 M. Presuming that rental is split evenly between the commuter services and the Rail system, the share of the latter would be $1,65 M/year.

Rental for land from km 5 to km 10 would be (for a width of 15 m): $950 000/year; from km 10 to 15, $168 000/year; from km 15 to 20, $25 000/year; from km 20 to 25, $5 600/year. From then on, rental would be $320/km/year. A total of 171,09 ha must be rented.

Summing up, the annual rental for right-of-way space from the Railways would amount to $2,8 M per year. This will be treated as an operating expense.

5.5.3 Track: Rail, Ties, Fasteners

Experience in Japan and France (1, 2, 3) suggests that a track made of continuously-welded rail (CWR) at 60 kg/m (121 lbs/yard) should be used throughout the line to obtain a long-lasting track structure. The use of CWR, rather than that of conventional bolted rail, is considered essential to obtain a smooth ride at high speed while reducing track and equipment maintenance costs.

The Rail system will require 179 600 m of double track for the exclusive use of HSR trains, as well as 5 400 m of new double track in the tunnel, to be shared with other rail traffic. In addition, 23 100 m of single track and 2 900 m of double track must be built to restore CN freight tracks relocated during construction. There could also be significant cost advantages to building, at the same time, 25 800 m of double track for the exclusive use of commuter services; this has not been considered.

The unit material cost for rail in standard lengths is $630/t, that is $0.63/kg or $75.90/m of single track. Adding transportation costs and the cost of flash butt welding (at $4/weld, 1,4 weld/t), CWR rail delivered to the site will cost $850/t or $102 per meter of single track.

The project requires a total (single) track length of 398,9 km: 185 km of double track for the Rail system, 23,1 km of single freight track and 2,9 km of double freight track; track for commuter services is excluded (Table E-11). Adding 5% for emergency sidings and storage tracks, the total material quantity is 418 845 m and the total cost would amount to $42,7 M for 50 620 t of CWR delivered.

The CWR should be laid on concrete ties; these ties, of monoblock design, built with prestressed and reinforced concrete, would be spaced 60 cm apart.

To date, in addition to Japanese National Railways (JNR) and numerous European Railways, Canadian National and several American Railroads have gathered experienced on concrete ties over a period of years (4,5,6). Their studies have shown that concrete ties provide a measurable increase in the capacity of the track structure to retain a stringent geometry when used for high speed: this feature is of prime importance to ensure that a good ride quality is maintained consistently. Based on these studies, it is possible to anticipate that, in Canadian service, concrete ties would provide an average service life of 40 to 50 years before needing replacement.

The CWR would be fastened to the concrete ties using spring clips, cant shoulder inserts, tie pads, and separate insulators. A stringent testing and quality control program will be developed and enforced during production and construction to ensure a product of the highest quality.

The unit material cost for one prestressed concrete tie is \$40, based on current prices and the quantities envisioned for this project. This amounts to a cost of \$66 666 per single track kilometer. For the whole project, considering an 8% margin for storage tracks and as a provision for wider ties at turnouts, the equivalent of 718 000 standard ties would be needed, at a purchase price of \$28,72 M.

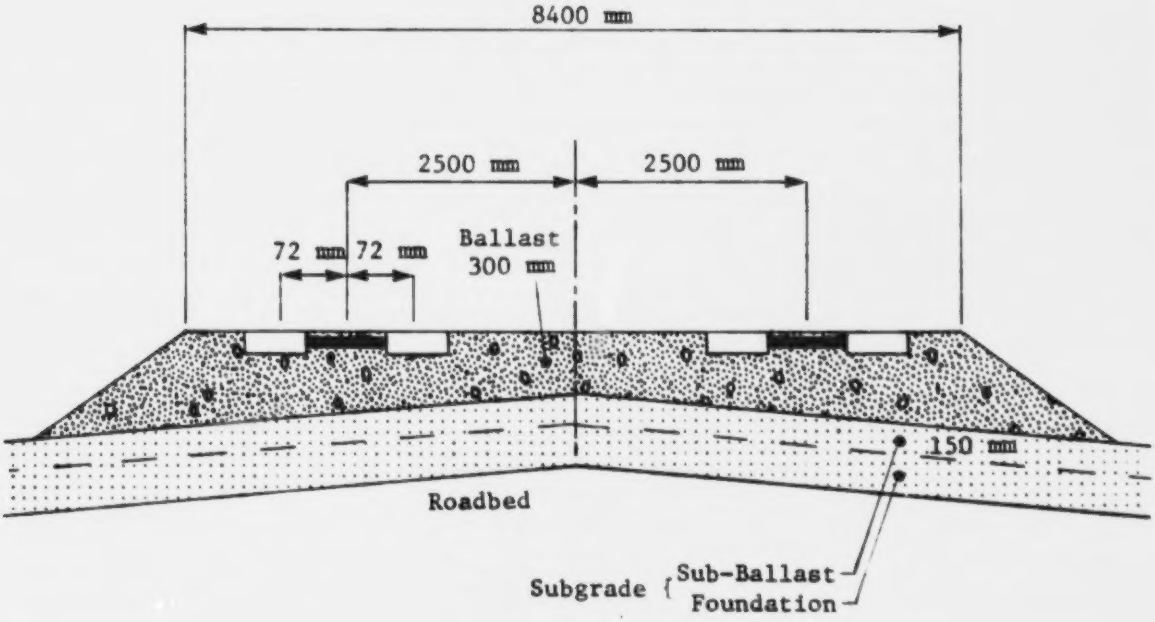
Fasteners will cost \$33/m of single track when purchased and delivered for a total project cost, using a 5% margin, or \$13,82 M.

5.5.4 Track Structure Design

In this study, the required thickness of ballast and sub-ballast, as well as the nature and thickness of the roadbed and the various layers of track foundation was determined based on designs developed for high speed passenger service. These designs take into account the expected rail traffic volume and the nature of the sub-soil (7).

For purposes of selecting a suitable type of track foundation, sub-soil along the Rail route was subdivided into one of four quality levels based on its nature, its materials, its geotechnical configuration, and the foreseeable long-term soil moisture. The qualification was done based on the results of borings and soundings conducted for various construction projects, as explained in Sub-section E.3.3:

- the S_0 quality applies to soils consisting of organic material that is improper for track foundation and must be removed or drained to raise the quality to S_1 standards; around 4 900 m of the route consists of such soil, which must be replaced over a 1 to 2 m depth: this is approximately 2,6% of the proposed route, by length.


8400 mm
2500 mm
2500 mm
72 mm
72 mm
Ballast
300 mm
150 mm
Roadbed
Subgrade
Sub-Ballast
Foundation

Subgrade Thickness:

- **good roadbed: 350 mm**
- **bad roadbed : 600 mm or more**

Figure 5-4 Track Structure Designs

- the S_1 soil quality is used to designate sensitive soils that have a low bearing capacity; it is found along 87 150 m of the route (47,1%);

- soils of S_2 quality have "average" properties; they are found along 58 500 m of the route (31,6%);

- the S_3 soil has a good bearing capacity; it is found along 31 950 m of the route (17,3% of the route length).

All track sub-ballast will rest on a 30 cm roadbed, obtained from a 95% compaction of the local soil, provided it is at least of S_1 quality.

If the sub-soil is of S_0 quality, it must be removed to be replaced by soil of S_1 quality.

If the sub-soil is of S_1 quality (whether originally or as a result of replacement of S_0 soil), the roadbed will first be covered by a 15 cm layer of granular material (to prevent contamination from the S_1 roadbed), then by a 15 cm layer as a foundation, then by sub-ballast and ballast.

If the sub-soil is of quality S_2, there will be only the 15 cm foundation layer between the roadbed and sub-ballast.

If the soil is of quality S_3, the sub-ballast will be laid directly on the roadbed.

In all three cases, the track structure, placed over the roadbed, will consist of 30 cm of ballast and 15 cm of sub-ballast. This information is summarized in Figure 5-4.

5.5.5 Track Construction

Track construction would be done in four steps.

The first step consists of site preparation, from wood clearing to roadbed compaction, through topsoil and earth removal and fill placement. The quantities have been calculated from an analysis of the Rail route profile shown in Appendix D; they amount to:

- 66 ha of wood clearing at $4485/ha;
- 40 300 m^3 of rock excavation at $30/$m^3$;
- 1 091 000 m^3 of top soil removal at $2/$m^3$;
- 4 845 000 m^3 of earth removal at $2/$m^3$;
- 4 430 000 m^3 of fill at $7/$m^3$(in place and compacted to 95% OCR).

Based on the above quantities and unit costs, the total cost for site preparation would amount to $44,4 M.

The second step of track construction would consist of placing the foundation where needed as outlined in the preceding sub- section. A total of 1 141 000 m^3 of foundation material will be needed, at a unit cost in place of $15/$m^3$, for a total of $17,12 M.

The third step would consist of placing the necessary thicknesses of sub-ballast and ballast. This will require 2 698 000 m^3 of sub-ballast and 805 000 m^3 of ballast. At a unit cost of $15/$m^3$ in place, this step will cost $52,55 M.

The fourth and last step will consist of laying the track and fencing the right-of-way. The unit price for laying the rails and tampering the ballast is $30/m of single track (including amortization or rental of automated tracklaying equipment). With a 5% margin, this implies $12,56 M for the total project.

The right-of-way will be fenced using a conventional chain link fence, 6 feet high, with three barbed wires, at a cost in place of $42/m. Fence will be needed for the complete route except for the tunnel and bridges. With a provision for storage yards, approximately 370 km of fence will be needed, at a total cost of $15,54 M.

5.5.6 Turnouts

The location of turnouts for the Rail system can be seen on the summary track layout, Figure 5-3.

As a modern operating practice is envisioned for the Rail system, on-board operating personnel should not have to leave the train to throw switches except in the rare case of a malfunction of the turnout motor or command system. All turnouts on the Rail route will thus be power-operated and remote-controlled: the position of their blades will be detected by the signaling system and set from the central operating control.

All turnouts exposed to the weather will be equipped with snow melting apparatus that will be actuated automatically by temperature and/or remote-controlled from the center.

Geometrically, turnouts will differ according to the maximum speed at which high speed trains are expected to travel over and across them.

Turnouts located on the main line will be such that high speed trains can crossover from one track to the other without significantly reducing speed: these will be European-type moveable-frog turnouts allowing a 200 km/h speed over the turnout and 160 km/h through it. There will be a total of 32 such turnouts, 30 of them making up 15 single crossovers. In the interest of reducing costs, double crossovers will actually be built as a succession of two single crossovers unless it was found that there is not enough space in the track section where they should be located.

Turnouts located where trains will normally travel at a reduced speed, such as near stations, as well as turnouts governing entry into and exit from the emergency sidings at km 96 and 140 will be designed to a lower operating speed. There will be a total of 34 low speed turnouts, 20 of them making up 10 single crossovers. These turnouts will all be power-operated, remote-controlled, and, if exposed to the weather, equipped with snow melters.

As the existing freight track is being rebuilt, a total of 17 turnouts will be needed. These will be used exclusively by CN freight trains for access to wayside industries, Doney Spur, and Cartierville Spur; they will be manually operated and low speed.

Finally, a total of 19 diamond crossings will be needed, most of them to allow level crossings between CN or CP tracks and the Rail system tracks. These diamonds will be found at the following kilometric points (approximately): 5, 11, 37, 95, 151, 184.

Costs for turnouts were obtained from manufacturers. The unit costs of turnouts in place, including all mechanical and electrical equipment (but excluding signalling controls) are the following: $300 000 for a high-speed turnout with moveable frog, $70 000 for a low-speed turnout, $60 000 for a diamond crossing, $48 000 for a manual turnout.

Total price for on-line turnouts would thus be $13,94 M. Adding 6 low-speed automatic turnouts for storage and workshop tracks would bring this total to $14,72 M.

5.5.7 Capital Costs for Infrastructure

The information on capital costs presented up to now in Section 5.5 has been summarized in Table 5-2. Contingencies of 20% were added to cover the imprecisions in quantity estimation for site preparation and track base materials.

The time staging of these investments has been programmed for starting operations on January 2, 1991. The time-staging of investments for the Rail system is discussed in Chapter 7.

In addition to capital costs, recurring costs will be incurred for the infrastructure. These consist of operational costs (Section 5.9), maintenance costs (Section 5.10), and land rental costs, which were discussed in Sub-section 5.5.2.

Table 5-2

Capital Costs for Rail Infrastructure

Item (Reference in Text)	Quantity (Unit Specified)	Unit Cost (as Specified)	Total Cost (CDN $/1983)
RIGHT-OF-WAY ACQUISITION			
Rural Land (5.5.2)	239,00 ha	$ 2 000 / ha	$ 0,5 M
Urban Land (5.5.2)	0,25 ha	$ 53 800 / ha	$ 0,0 M
Building Expropriation	21 u.	$ 100 000 ea.	$ 2,1 M
Sub-Total			$ 2,6 M
TRACK COMPONENTS (Delivered)			
Rail (5.5.3)	418 845 m	$ 102 / m	$ 42,7 M
	(50 260 t)	($ 625 / t)	
Ties (5.5.4)	718 000 u.	$ 40 ea.	$ 28,7 M
Fasteners (5.5.4)	418 845 m	$ 33 / m	$ 13,8 M
Sub-Total			$ 85,2 M
SITE PREPARATION			
Wood Clearing	65,6 ha	$ 4 485 / ha	$ 0,3 M
Rock Excavation	0,04 Mm^3	$ 30 / m^3	$ 1,2 M
Topsoil Removal	1,09 Mm^3	$ 2 / m^3	$ 2,2 M
Earth Removal	4,85 Mm^3	$ 2 / m^3	$ 9,7 M
Fill in place	4,43 Mm^3	$ 7 / m^3	$ 31,0 M
Contingencies (20%)			$ 8,9 M
Sub-Total			$ 53,3 M
TRACK BASE MATERIALS (in place)			
Foundation material	1,14 Mm^3	$ 15 / m^3	$ 17,1 M
Sub-ballast	2,70 Mm^3	$ 15 / m^3	$ 40,5 M
Ballast	0,81 Mm^3	$ 15 / m^3	$ 12,1 M
Contingencies (20%)			$ 13,9 M
Sub-Total			$ 83,6 M
TRACK CONSTRUCTION			
Track Laying	418 845 m	$ 30 / m	$ 12,6 M
Fence	370 000 m	$ 42 / m	$ 15,5 M
Sub-Total			$ 28,1 M
TURNOUTS			
High Speed Automatic	32 u.	$ 300 000 ea.	$ 9,6 M
Low Speed Automatic	40 u.	$ 70 000 ea.	$ 2,8 M
Manual (#4)	17 u.	$ 48 000 ea.	$ 0,8 M
Diamond Crossings	19 u.	$ 60 000 ea.	$ 1,1 M
Sub-Total			$ 14,3 M
TOTAL (CDN $ M, 1983)			$ 267,1 M

5.6 Structures

This section describes and enumerates the various structures found on the Rail system as defined. The first sub-section describes grade separation structures, with emphasis on typical designs used repeatedly throughout the route. The second sub-section describes one-of-a-kind structures used for grade separation under special conditions or using a special design. The third sub-section discusses bridges and culverts, while the last one presents cost estimations for all structures.

5.6.1 Typical Grade Separations

To achieve a high degree of safety with the speeds and frequencies envisioned, all grade crossings must be eliminated from the Rail route. To do so, some cross roads will be closed and, at others, various types of grade separation structures will need to be introduced, as shown in Table 5-3. Every effort should be made to use standard structure design wherever possible.

In urban areas, the typical grade separation for streets will be a four-lane underpass with sidewalks (Figure 5-5), which is the usual designs for that function. For streets that will be closed, a pedestrian overpass might be built if necessary.

In rural areas, the typical grade separation for highways and paved roads will be a standard two-lane road-over-Rail concrete overpass; for provincial highways, a wider structure of similar design will be used.

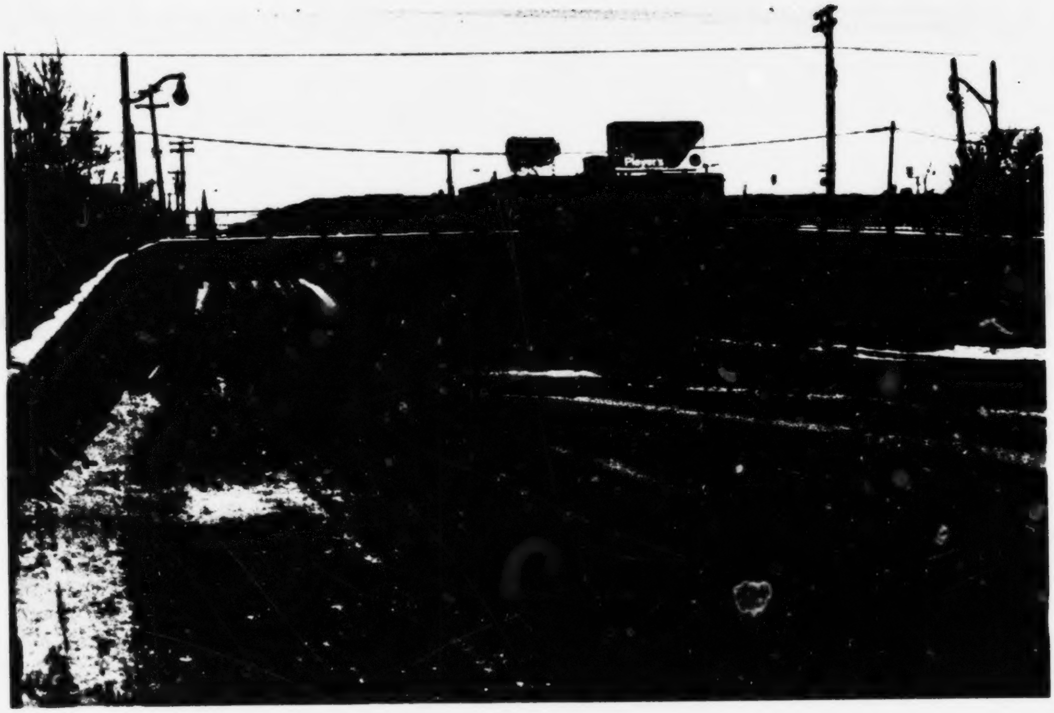


Figure 5-5 Typical Street-Under-Rail Grade Separation

Table 5-3

Treatment of Cross Roads for Rail System Definition

Context and / or Application		Number and Proportion of Cross-Roads						Total Number
		Closed		Detoured		Grade-Separated		
		#	%	#	%	#	%	
SYSTEM DEFINITION	Urban Areas	3	10	2	6	26	84	31
	Rural Areas	26	34	10	13	40	53	76
	Total	29	27	12	11	66	62	107
REFERENCES	Highway 417[1]	24	31	16	21	37	48	-
	CIGGT[2]	-	35	-	15	-	50	-

Notes: 1. Highway 417 as built, from Pointe-Fortune to Ottawa.
2. CIGGT Recommendation in Alternatives to Air Study (6).

Figure 5-6 Typical Highway-Over-Rail Grade Separation

No structure will normally be built at gravel road crossings: unless they have an important connection function, these roads will be closed off. If they do, a narrower version of the highway-over-Rail structure could be used. Whereas overpasses (or level crossings) are normally used for such applications, the use of underpasses should also be investigated as they might be cheaper, especially if, for low-volume roads, a low vertical clearance could be used.

The total requirements for grade separation structures for the Rail system are given in Table 5-4.

5.6.2 Special Structures

Special structures, requiring innovative design and analysis for their construction and economic optimization, are found in three locations on the Rail route:

- in the center of the Town of Mount Royal, where existing street-over-rail structures must be rebuilt with retaining walls to accomodate the widening of the cut in which the route is laid;
- at Eastern Junction, where the CN Saint-Laurent and Mount Royal Subdivisions must be grade-separated;
- at Mirabel, where a tunnel is needed for access to the Rail station and to pass under a major taxiway.

The difficulty in the Town of Mount Royal is the limited space available for construction: the right-of-way is bordered by residential streets on both sides, and the track is built in a cut. Other than limited maneuverability and the need to support the bordering streets at all times, the structures are standard in design. The direct capital cost of the overpasses and the retaining walls was estimated at $1,3 M.

Table 5-4

Requirements for Typical Grade Separation Structures

Type of and / Structure	Size of Structure		New Structures		Rebuilt Structures		Total number
	Number of Tracks	Number of Lanes	Piles	Foot-ings	Piles	Foot-ings	
Street-under-Rail	5	2	-	3	-	-	3
	5	4	1	6	3	2	12
	Any	Any	1	9	3	2	15
Highway-over-Rail	2	2	5	7	-	-	12
	3	2	7	6	2	2	17
	3	4	-	1	-	1	2
	Any	Any	12	14	2	3	31
Road-over-Rail	2	2	1	-	-	-	1
	3	2	7	6	-	-	13
	Any	Any	8	6	-	-	14
ALL	Any	Any	21	29	5	5	60

The difficulty with grade-separating Eastern Junction is the need to maintain traffic on both subdivisions at all times: this requires the construction of a long temporary track. Furthermore, as the level of Saint-Laurent Subdivision must be raised while the grade is kept at 1%, the roadbed work will extend over a long distance and involve raising a small yard at Saint-Laurent. The direct capital cost of the structure and the trackwork is estimated at $1,9 M.

Finally, the most important structure is a tunnel for underground access to the Mirabel Airport Station in the basement of the Terminal building: the Rail route must pass under several buildings, roads, and a major taxiway. The functional length of the tunnel must be at least 1500 m. Although solid bedrock is found at 3 to 6 m under the surface in the area, the rock cover above the excavation would not be sufficient unless the tunnel is unduly lengthened.

The solution adopted is to build a reinforced concrete structure designed to support the loads of the taxiway under which the route passes. Considering the approaches to the tunnel, that structure will be 1880 m long and will require an excavation cross-section of 126,8 m^2. The cost of rock excavation will be $6337/m and the cost of the structure, $10 040/m. Adding a grade separation structure at Côte Saint-Jean, the direct capital cost of the tunnel will amount to $34,4 M.

5.6.3 Bridges and Culverts

The width of river crossings to be bridged along the Rail route ranges from 10 to 800 m; structures will need to carry 2, 3 or 5 tracks, depending on their location.

Whenever the crossing is shorter than 10 m, only a culvert will be used.

For spans up to 100 m, the following three typical structures would be used:

- for very short bridges with a 10 m span: a composite deck, made of reinforced concrete and standard WF steel shapes, being simply-supported on reinforced-concrete abutments; there would be nine structures of that type;
- for short bridges with a 40 m span: a composite deck, made of reinforced concrete and custom-welded plate steel beams, being simply- supported on reinforced concrete abutments; there would be one structure of this type;
- for medium-length bridges of 100 m span: a simply- supported steel truss with ties laid directly on the structure; there would be two structures of this type.

The very short bridge costs $800/m^2 when built on footings and $1 000/m^2 when built on piles. Five of these bridges will be built new for 2 tracks, using pile foundations; they will cost $120 000 each for a 120 m^2 deck. The four others will be built for three tracks; all will replace an existing bridge and will be built while rail traffic is maintained; that will double the unit cost. Three will be built on piles at a cost of $340 000 each (for 170 m^2); one on footings at a cost of $192 000. The total construction cost for these nine 10 m bridges is thus estimated at $2,3 M.

A 40 m bridge built on piles will cost \$1450/m^2 if new. There is one such bridge, carrying three tracks, for a deck area of 680 m^2. This bridge being built to replace an existing bridge, the unit cost must be doubled, so the capital cost is estimated at \$2,0 M.

An engineering estimate has been prepared for 100 m span bridges consisting of a steel truss on pile foundations, two of which are required. Each bridge, being built new to carry two tracks, would cost \$1,85 M.

Given the crossing locations envisioned for longer bridges, there are no navigation problems; also ice accumulation problems are not expected to be extreme. As a result of these favorable conditions, bridges to cross Rivières des Prairies and Rivière des Mille Iles could be built as a succession of simply-supported 100 m spans, based on the structural concept outlined above.

This would result in direct capital costs of \$14,9 M for each crossing. As each river is divided into two branches of similar widths in each case (200 m and 120 m), the same succession of spans can be used in both cases: two 100-m steel trusses on the wider branch, and a steel truss with a 20-m composite deck on the narrower branch.

Due to the necessity of maintaining electrified rail commuter service during construction, and considering that the steel truss envisioned can carry no more than 3 tracks, two parallel series of trusses would be built in each case. Existing bridges would be demolished after the first series is commissionned.

In the case of the Ottawa River crossing, the new bridge will carry two tracks. The crossing is 725 m wide, but a clearance above waterline of 13 m minimum must be maintained. Furthermore, there is advantage to lengthening the structure to pass over highways bordering the river on both shores. The resulting structure would be effectively 1120 m long and cost \$22,4 M.

A total of 46 culverts will be needed to bridge streams, creeks, and irrigation ditches; thirty-three of them will replace an existing structure.

The average cost of culverts is estimated at $120/m, whether for a new construction or replacement of an existing culvert*. The total length being 1110 m (Table E-22), the cost is estimated at $0,2 M.

5.6.4 Capital Costs for Structures

The cost of a structure is conditioned by the loads, the dimensions, the sub-soil conditions, and local conditions imposing constraints on the construction methods, if any.

For all typical structures used for grade separation, local conditions are considered not to pose any constraints. Sub-soil conditions are classified as either "good", requiring footings only, or "bad", requiring piles for columns and abutments. The construction cost will thus vary between two values depending on sub-soil, the dimensions of the structure, and whether it carries rail or road traffic.

Unit costs (in $\$/m^2$ of deck area) were developed for each type of structure and each sub-soil condition. The cost of each typical design was then calculated based on its estimated dimensions; the result is shown on Table 5-5. The number of structures of each type was shown in Table 5-4. The direct cost for typical structures amounts to $18,7 M; it can be obtained by multiplying corresponding data in Tables 5-4 and 5-5.

---

* These unit costs, which appear low, do not include the costs of earthwork and track construction, which are accounted for elsewhere.

The direct cost of special structures was given in Sub-section 5.6.2, it amounts to \$37,2 M; that of bridges, in Sub-section 5.6.3.

The direct cost of bridges and culverts is given in Sub-section 5.6.3; it amounts to \$60,4 M.

Finally, the cost of street and road reconstruction must be added. It involves 610 000 m^3 of road foundation, costing (at \$15/m^3 in place) \$9,2 M and 169 000 tonnes of asphalt (at \$30/ton) costing \$5,1 M.

The cost of structures is summarized in Table 5-6. It amounts to \$156,8 M with contingencies.

Table 5-5

Unit Costs for Grade Separation Structures

Type	Size		Condition	Foundation	Size (m)	Cost ($1 000)
	Tracks	Lane				
STREET-UNDER-RAIL - $625/m^2$ on footings - $825/m^2$ on piles - 100% more for rebuilt	5	2	New	Footings	-	455
		4	New	Piles	728	600
				Footings	728	455
			Rebuilt	Piles	728	1 200
				Footings	728	910
HIGHWAY-OVER-RAIL - $800/m^2$ on footings for 2 tracks - $1050/m^2$ on piles for 2 tracks - $700/m^2$ on footings for 3 tracks - $900/m^2$ on piles for 3 tracks - when three tracks four lanes, same unit costs as two tracks two lanes - 50% more for rebuilt	2	2	New	Piles	178	187
				Footings	178	142
	3	3	New	Piles	244	219
				Footings	244	171
			Rebuilt	Piles	244	328
				Footings	244	257
		4	New	Footings	512	408
			Rebuilt	Footings	512	613
ROAD-OVER-RAIL - 70% of cost of equivalent Highway-over-Rail	2	3	New	Piles	-	131
	3	2	New	Piles	-	153
				Footings	-	120

Table 5-6

Capital Cost for Rail Structures

Item (Reference in Text)	Quantity (Unit Specified)	Unit Cost (as Specified)	Total Cost (CDN $ M, 1983)
GRADE SEPARATIONS (5.6.1)			
Street-under-Rail - New	10 u.	$ 470 000 ea. av.	$ 4,7 M
- Rebuilt	5 u.	$1 080 000 ea. av.	$ 5,4 M
Highway-over-Rail - New	26 u.	$ 188 000 ea. av.	$ 4,9 M
- Rebuilt	5 u.	$ 356 000 ea. av.	$ 1,8 M
Road-over-Rail - New	14 u.	$ 143 000 ea. av.	$ 2,0 M
Road reconstruction - Foundation	0,60 Mm^3	$ 15 / m^3	$ 9,2 M
- Asphalt	0,17 Mt	$ 30 / t	$ 5,1 M
Contingencies (20%)			$ 6,6 M
Sub-Total			$ 39,7 M
SPECIAL STRUCTURES (5.6.2)			
Town of Mount Royal	1 u.	Global	$ 1,3 M
Eastern Junction	1 u.	Global	$ 1,5 M
Tunnel at Mirabel	1 u.	Global	$ 34,4 M
Contingencies (20%)			$ 7,4 M
Sub-Total			$ 44,6 M
BRIDGES AND CULVERTS (5.6.3)			
10 m Spans (2)	9 u.	$ 250 000 ea.	$ 2,3 M
40 m Spans (2)	1 u.	Global	$ 2,0 M
100 m Spans (1)	2 u.	$ 1,85 M	$ 3,7 M
Rivière-des-Prairies	1 u.	Global	$ 14,9 M
Rivière-des-Mille-Iles	1 u.	Global	$ 14,9 M
Ottawa River	1 u.	Global	$ 22,4 M
Culverts (1 m Ø)	1 000 m	$ 120 / m	$ 0,1 M
Culverts (2 m Ø)	100 m	$ 600 / m	$ 0,1 M
Contingencies (20%)			$ 12,1 M
Sub-Total			$ 72,5 M
TOTAL CAPITAL COST (CDN $ M, 1983)			$ 156,8 M

5.7 Stations

The Rail system will have four stations: Montreal Terminal, West Island Station, Mirabel Airport Station, and Ottawa Terminal; their location is described in Sub-section 4.2.2.

The Montreal Terminal will be at Central Station. Tracks 13 and 14 and the platform between these tracks will be used exclusively for the Rail service; the existing arrangements will be renovated. Renovation work will consist of replacing the existing stairs (between the underground platform and the street-level waiting area above) by two escalators and one elevator for use by handicapped travelers; new control areas will be added for ticket control near the entrance to and exit from the new escalators. The cost of these renovations is estimated at $0,8 M. On the concourse level, operating the Rail service will require a total space of 423 m^2 for a waiting area, ticket counters, control area, etc. This space could be rented from Canadian National at an estimated cost of $80 000/year.

At West Island Station, the new station building will be on the South side of the right-of-way and lateral platforms will be used on account of the short headway between arriving and departing trains during peak periods. The inside platform (incoming trains) will be accessed directly from the station building, while the outside platform (outgoing trains) will be accessed through a tunnel; the stairs in that tunnel will be equipped with an incline elevator for wheel chairs. The station facility will consist of these two platforms, a building covering an operational area of 263 m^2, a parking lot for 200 cars, and a curb area for taxi and bus loading and kiss-and-ride. The total construction cost is estimated at $0,68 M.

At Mirabel Airport, the station will be located in the basement of the Terminal Building, which was designed with this possibility in mind. Due to short headways between trains in opposite directions and to facilitate conflicting passenger movements in and out of each train, two lateral platforms and a central platform are needed. Each platform will be equipped with two escalators and, in addition, the central platform will be equipped with an elevator for use by handicapped travelers. On the level above the platforms, an operational area of 161 m^2 will be needed for waiting, ticket sales, and operational offices. It is presumed that this space will be made available free of charge by Transport Canada. The cost of building the platforms and making the necessary modifications to the building is estimated at $1,13 M.

At Ottawa Terminal, for operational flexibility, two lateral platforms and a central platform will be built. The lateral platform nearest the building, normally used for incoming trains, will be accessed directly from the existing building, which will not be modified. A new tunnel will be built to link the two other platforms with the waiting area; two stairs in this tunnel will be equipped with an incline elevator for wheel chairs. Space required for operating the service is estimated at 584 m^2 and the corresponding rental at $126 000/year. The cost of the station equipments is estimated at $0,34 M.

Direct capital costs for stations are summarized in Table 5-7.

In Central Station, at Mirabel, and at Ottawa Terminal, existing facilities and services will be made available to travelers. The charge for their use is included in the estimated rental cost; these facilities include: ticket counters, food and drink services, seats, various distributing machines, toilets, baggage lockers, etc. Provision of similar equipment at West Island Station is included in the capital cost.

Provision of computer terminals and associated hardware for ticket sales is included in the station operation cost.

Table 5-7

Capital Costs for Rail Stations

Item (Reference in Text)	Quantity (Unit Specified)	Unit Cost (as Specified)	Total Cost (CDN $ M, 1983)
MONTREAL TERMINAL AT CENTRAL STATION (5.7.1)			
Structural Work	Global	-	$ 0,14 M
Escalators and Elevators	5 u.	$ 120 000 ea.	$ 0,60 M
Control Counters	2 u.	$ 30 000 ea.	$ 0,03 M
Finishing	Global	-	$ 0,03 M
Contingencies (5%)			$ 0,04 M
Sub-Total			$ 0,84 M
WEST ISLAND STATION (5.7.2)			
Land Acquisition	6 000 m^2	$ 27 / m^2	$ 0,16 M
Platforms	1 200 m^2	$ 100 / m^2	$ 0,12 M
Station building	275 m^2	$ 550 / m^2	$ 0,15 M
Parking lot	200 spaces	$ 11 / m^2	$ 0,07 M
Outside Finishing	Global	-	$ 0,10 M
Tunnel with incline elevator	Global	-	$ 0,08 M
Contingencies (5%)			$ 0,03 M
Sub-Total			$ 0,71 M
MIRABEL AIRPORT STATION (5.7.3)			
Structural Work	Global	-	$ 0,10 M
Platforms	2 100 m^2	$ 100 / m^2	$ 0,21 M
Escalators and Elevators	6 u.	$ 120 000 ea.	$ 0,72 M
Interior finish	Global	-	$ 0,10 M
Contingencies (5%)			$ 0,02 M
Sub-Total			$ 1,15 M
OTTAWA TERMINAL (5.7.4)			
Structural Work	Global	-	$ 0,10 M
Platforms	1 800 m^2	$ 100 / m^2	$ 0,18 M
Tunnel with incline	Global	-	$ 0,05 M
Finishing Work	Global	-	$ 0,01 M
Contingencies (5%)			$ 0,02 M
Sub-Total			$ 0,36 M
TOTAL (CDN $M, 1983)			$ 3,10 M

Note: Details are found in Table E-24.

5.8 Power and Control Equipment

5.8.1 Power Supply

The fundamental parameter in defining the power supply equipment is the location and capacity of the feed points required; these are determined from voltage drop and loading considerations, based on the expected train loads and the catenary system used.

From the above considerations, the maximum section length that one feed point can supply would be between 45 and 50 km. From a consideration of the proposed Rail route and the location of existing transmission facilities (Figure 1-1), the obvious location of feed points is where Hydro-Quebec or Hydro-Ontario stations are located close to the track; that is at the following sites:

- at km 15 of the route, near Saraguay, the Hydro-Quebec Saraguay 315/120 kV Substation (another possible site would be the Fleury 120 kV Substation located approximately 2,5 km from the track);
- at km 80, near St-André-Est, the Hydro-Quebec Carillon 120 kV Hydro Generating Station;
- near km 176, near Blackburn Siding, where the Hydro-Ontario 230 kV double circuit line from Hawthorne to Masson crosses the Rail route.

The above three feed point locations would result in a maximum section length of 48 km, between Carillon and the Blackburn Siding feed point. This section length could be reduced, if detailed studies show a need. The above arrangement with three feed points should be considered the absolute minimum requirement for the present and expected traffic, speed levels, and frequencies.

Duplicate transformers are provided to allow for loss of one transformer. Loss of supply to a complete station would, however, result in considerably reduced system performance. No problems are foreseen for the supply utilities in accepting the single phase train loads.

Special arrangements may be required at the Montreal and Mirabel terminations because of the tunnel sections. These are discussed in Appendix E, Section E.7.

Capital costs for power supply equipment are given in Table 5-8.

5.8.2 Power Distribution

Until the construction (now in progress) of a new electrified line in British Columbia, no catenary has been built in Canada, except in rare cases, for short lines, such as the 1917 construction of the Mount Royal tunnel and the electrification of an 11-km section of the Quebec North Shore & Labrador Railway in the 1960's. Numerous studies, however, have been performed concerning power distribution lines specially designed for Canadian climatic conditions.

As these studies became more sophisticated and could build on one another, it became clear that a "Canadian" catenary would not be strikingly different in concept, in techniques, in dimensions, and in cost, from a catenary built in Scandinavia, for instance, for comparable traffic conditions. By making the necessary adjustments for the relative prices of materials and labour, it became possible to obtain progressively more precise construction cost estimates.

The catenary envisioned as a basis for the cost estimates would be designed based on appropriate standards (such as UIC 660.3, CSA C22.3, ASTM B-47, B-229); it would have the following characteristics:

- a 4/0 EK Copper-copperweld carrier cable, with a 150 mm^2 solid copper contact wire;

- a Y-type suspension to reduce contact losses;

- automatic counterweight tension adjustment for a maximum sag of 5 to 25 cm;

- a typical span of 60 m between supports.

Based on very recent Canadian studies, the most appropriate value to use as a unit cost for an estimate in this study is $200 000 per kilometer of double track.

This value is a good average for the whole line; it takes into account that the construction of catenary bridges will be necessary in some sections (from km 5,4 to km 28,0, in part). The unit cost also presumes the use of modern construction techniques and methods, with foreign assistance for design.

This point should be stressed briefly. It has been found that, with experience, significant savings can be achieved in the construction cost of a catenary. In England for instance, one has observed a reduction in real cost of 45% over a period of 20 years. Use should be made of European assistance of such nature, also available from France and Germany. If, for reasons of developing a Canadian design expertise, one opted for "starting from scratch", a significantly higher unit cost should be used to reflect the price for learning and the amortization of research and development costs.

Based on a unit cost of $200 000/km (double track), a route length of 185 km, and an addition of 5% to cover sidings, yards and shops, the cost of catenary construction should be $38,9 M.

Table 5-8

Capital Costs for Rail Power Supply and Distribution Equipment

Item (Reference in Text)		Quantity (Unit Specified)	Unit Cost (as Specified)	Total Cost (CND $ M, 1983)
SUBSTATIONS (3)				
Tranformers (6/8/10 MVA)		3 u.	$ 180 000 ea.	$ 0,54 M
Buildings, Protections, Controls		3 u.	$ 250 000 ea.	$ 0,75 M
Circuit Breakers (25 kV)		15 u.	$ 16 000 ea.	$ 0,24 M
HV Circuit Breakers	-120 kV	1 u.	$ 160 000 ea.	$ 0,16 M
	-230 kV	1 u.	$ 250 000 ea.	$ 0,25 M
	-315 kV	1 u.	$ 350 000 ea.	$ 0,35 M
Contingencies (20%)				$ 0,46 M
	Sub-Total			$ 2,75 M
PHASE BREAKS (2)				
Circuit Breakers (25 kV)		10 u.	$ 16 000 ea.	$ 0,16 M
Civil, Protection, Control		2 u.	$ 100 000 ea.	$ 0,20 M
Contingencies (20%)				$ 0,07 M
	Sub-Total			$ 0,43 M
TERMINAL STATIONS (2)				
Circuit Breakers (25 kV)		2 u.	$ 16 000 ea.	$ 0,03 M
Buildings, Protections, Controls		2 u.	$ 50 000 ea.	$ 0,10 M
Contingencies (20%)				$ 0,03 M
	Sub-Total			$ 0,16 M
TOTAL CAPITAL COST (CDN $M, 1983)				$ 3,34 M

5.8.3 Command and Control

The command and control sub-system, consisting of centralized, wayside, and on-board equipment, will perform the following functions for the safe and efficient operation of the Rail system:

- preventing tail-end collisions by ensuring, with the aid of fail-safe track signal blocks, that a safe distance is automatically maintained between two successive trains;
- preventing sidesweep and head-on collisions by ensuring that turnouts, controlled from a central location, are set and locked in the appropriate position, according to pre-established routes that all trains must adhere to;
- preventing derailments by automatically maintaining, at any point along the track, a train speed that is safe with respect to local conditions and by detecting overheated journal bearings (hot boxes) with the aid of wayside equipment;
- supervising the whole operation in real time from a central point in order to rapidly report any unforeseen event, so as to assist in taking the appropriate action.

The system would be supervised from a central control point, from which the complete operation would be monitored and the position of turnouts and crossovers commanded. On-Board equipment would detect speed commands (there would be six, including 0 km/h for Stop) emitted by track circuits all along the route and issue a corresponding command for the engineman. If the engineman does not react and the train exceeds the speed command by a given amount, emergency brakes are applied automatically.

The equipment required to ensure these functions is listed in Table 5-9 and described in Section E.9. Its capital costs are given in Table 5-10.

Table 5-9

Summary of Command and Control Equipment Requirements

General Route Characteristics	
Length of Territory	185 km
Major Interlockings (controlled points)	10 u.
Minor Interlockings (CN and CP crossover points)	4 u.
Turnout Controls	
High Speed Turnouts (160 km/h across)	48 u.
Medium Speed Turnouts (50 km/h across)	4 u.
Hand-Thrown Electrically-Locked Turnouts	10 u.
Wayside Equipement	
Reversible Automatic Signal Blocks	175 u.
Hot Journal Detectors	10 u.
Test Points for On-Board Equipment	3 u.
Speed Commands (0, 80, 120, 160, 200, 250 km/h)	6 u.
On-Board Equipment	
(One equipment for each train)	9 u.

Table 5-10

Capital Costs for Rail Signalling Equipment

Item (Reference in Text)	Quantity (Unit Specified)	Unit Cost (as Specified)	Total Cost (CDN $ M, 1983)
WAYSIDE EQUIPMENT			
Typical Interlockings	9 u.	$ 1,8 M ea.	$ 16,3 M
Special Interlockings	4 u.	$ 2,5 M ea.	$ 10,1 M
Electric Locks	10 u.	$ 40 000 ea.	$ 0,4 M
Signal Blocks	175 u.	$ 44 000 ea.	$ 7,7 M
Hot Journal Detectors	10 u.	$ 37 800 ea.	$ 0,4 M
Contingencies (5%)			$ 1,7 M
Sub-Total			$ 36,6 M
CENTRALIZED EQUIPMENT			
Control Center Equipment	Global	-	$ 4,5 M
Sub-Total			$ 4,5 M
ON-BOARD EQUIPMENT			
Included in Cost of Vehicle		-	$ 0,0 M
Sub-Total			$ 0,0 M
TOTAL CAPITAL COST (CDN $M, 1983)			$ 41,1 M

5.8.4 Communications

Given the sophisticated command and control system just described, communication equipment will only add a voice capability that is not essential to the system safety, but quite useful for operational control.

This voice capability will be used for three major functions:

- provide complementary information to the system status date relayed to central control by the signalling system;
- allow communications with freight trains and work trains that are not equipped with on-board signalling equipment;
- provide a back-up mode for permitting limited system operation in the unlikely case of a major failure of the signalling system.

To these ends, communications requirements consist of:

- a base station ($ 1M)
- a radio set . at each of the four stations ($0,25M each)
  - . at the maintenance depot ($0,25M)
- one on-board radio set for each of ten trainsets ($0,1M each)
- mobile radios for mobile maintenance equipment ($0,25M total).

The total cost of the communication equipment described above would amount to $3,5 M. The cost is relatively low, as this is readily available equipment sold in a highly competitive market. Also, the number of trainsets and stations is quite low, compared to most transit systems, for instance.

5.8.5 Maintenance Building

The maintenance building would probably be located between Deux-Montagnes and Mirabel. In addition to providing covered space for preventative, scheduled, and unscheduled maintenance of the fleet, the building would also house the control center and administrative offices.

All equipment related to that building (storage tracks and catenary, turnouts, control computer, maintenance equipment, etc.) is described elsewhere. The assumed capital cost of $4,5 M covers only the cost of the building itself and that of the necessary office equipment.

5.8.6 Maintenance Equipment

A provision of $5,5 M has been made for fixed maintenance equipment to be located in the maintenance building. This is presumed to cover the cost of overhead cranes, wheel truing machines, and the like. Mobile maintenance equipment is discussed in Section 5.10.

5.9 Operating Procedures, Personnel, and Costs

The objective of this section is to present the evaluation of the staff required to operate the system and to estimate their salary costs, based on the operation procedures envisioned for the system.

For this purpose, operating personnel will be classified as follows: on-board personnel, station personnel, reservation personnel, system operation personnel.

For each group, three elements will be reviewed in the following order: specific procedures, staff requirements, salary costs. First, however, a brief review of system operating policies that impact on all classes of personnel.

5.9.1 Overview of System Operating Policies

The system will operate 7 days per week, 365 days per year. Everyday, the first departure will be at 6h30 in each terminal and the last, around midnight. All trains will stop at both intermediate stations. All stations will be open to the public from 6h00 to 1h30. Reservation services will be offered at stations and by telephone: telephone services will be available daily, from 9h00 to 22h00 on weekdays, and from 9h00 to 21h00 on weekends and holidays.

Salaries for operating personnel will be comparable to those currently paid by VIA, annual salary costs for various positions of interest are given in Table 5-11. These salary costs include vacation pay and other fringe benefits.

Table 5-11

Salary Costs for Rail Personnel

Function	Annual Salary Cost	Salary Cost per Hour
TRAIN PERSONNEL		
Engineman	$ 56 000	$ 33.65
Conductor	$ 52 000	$ 31.25
On-Board Service Agent	$ 26 000	$ 15.63
STATION PERSONNEL		
Station Manager	$ 56 000	$ 33.65
Stationmaster	$ 52 000	$ 31.25
Assistant Stationmaster	$ 40 000	$ 24.04
Ticket Agent	$ 31 000	$ 18.63
Ticket Taker	$ 31 000	$ 18.63
Baggage Handler	$ 31 000	$ 18.63
Janitor	$ 31 000	$ 18.63
COMMAND AND CONTROL PERSONNEL		
System Operation Manager	$ 52 000	$ 31.25
Terminal Supervisor	$ 43 000	$ 25.84
Dispatcher	$ 36 000	$ 21.63
Assistant Dispatcher	$ 31 000	$ 18.63
Signal Operator	$ 31 000	$ 18.63
Electrical Operator	$ 31 000	$ 18.63
OTHER PERSONNEL		
Reservation Agent	$ 31 000	$ 18.63
Clerk	$ 26 000	$ 15.63
Maintenance Agent	$ 29 000	$ 17.43

Notes:

1. Annual salary cost includes total salary paid to the employee including vacations and holidays) and the employer's cost for employee benefits such as life and sickness insurance, unemployment benefits, etc. This is equivalent to 17% of salary paid to employee.
2. The average productivity at VIA is 1664 hours / year.
3. Enginemen are now paid on a mileage basis by VIA Rail, but Amtrak has negotiated for and obtained agreement on the principle of an hourly wage. This recent change at Amtrak results from a widespread trend toward increased labor productivity in the railway. It will be presumed that, by 1991, enginemen on the Rail system are paid yearly or hourly and make as much as they make today on a mileage basis (in CDN 1983 dollars). Hence the $56 000.

5.9.2 On-Board Personnel

The crew of each train will be the following: a conductor, an engineman, and one service attendant per coach, as beverage and snacks will be available on board (their direct costs are presumed to be recovered from their sale and not discussed further). There will be no on-board ticket collection or control. As the train reverses direction in Mirabel and the station stop is only 90 s, there will be a change of engineman there at every trip.

All on-board personnel will report to their base station 60 min before their scheduled departure and will have minimum of 30 min between arrival and departure. Everyone will normally return to base every night. Conductors and service attendants will be based equally between Montreal and Ottawa, while the enginemen will be split in three groups between Montreal, Mirabel, and Ottawa.

A personnel assignment schedule has been worked out for enginemen. That assignment can cover the schedule with four teams working cyclically on a 4-3 basis (four days work, three days off, three days work, four days off). Teams of enginemen would cover the schedule from the three bases for a total system force of 42 enginemen. Based on Table 5-11, an annual average salary cost of $56 000 per engineman will be assumed. Total system cost for enginemen in 1991 would thus be $2,35 M/year (in 1983 dollars).

A different personnel assignment schedule has been worked out for conductors and stewards, based on a cycle of 28 days. Each steward or conductor would work up to 10h20 per day for 4 days, then be off three days, then work for three days, then be off for four days, then repeat the same schedule in reverse.

The proposed train schedule could be covered with two teams of 11 conductors and 44 stewards working from both terminals, for a total system force of 25 conductors and 100 stewards, including replacements for four-week vacations. When trains are operated with five coaches from 1999 on, 125 stewards will be required.

Based on Table 5-11, 1983 average annual salary costs of $52 000 for a conductor and $26 000 for an on-board service agent were assumed. Corresponding direct salary costs systemwide (in 1983 values) are estimated at $1,30 M/year for conductors and $2,60 M/year for service attendants ($3,25 M/year from 1999 on).

To direct salary costs must be added, based on practice at VIA, 4% for clerical personnel, 14% for supervision, and then 10% for materials costs, for a total cost for on-board personnel of $8,11 M/year ($8,96 M/year from 1999 on).

5.9.3 Station Personnel

The essential functions of a station, as this study is concerned, will be that of a ticket sales office and that of a waiting area. Any other functions such as service shops for passengers will be considered as self-supporting activities (including the recuperation of their appropriate capital costs) and will not be costed hereinafter. Limited baggage handling service will be available. Passengers will show their tickets to the ticket collector before acceding the platform upon departure and when entering the station from the platform upon arrival: these will be the only ticket controls. Initially, there would be a 100% control which could (and probably would) eventually be replaced with a honor system with 10-15% random control.

The following positions will have to be filled at each of the four stations:

- manager:	has the executive authority for managing the station;
- support staff:	provide administrative assistance to the station manager;
- stationmaster:	direct on-line authority for the day-to-day operation of the station;
- assistant stationmaster:	provides complementary supervision and assistance to station personnel where needed (such as assisting in ticket collection in peak periods);
- ticket agent:	ticket sales, credits, changes, transfers, and reservations using computerized equipment;
- ticket taker:	controls tickets upon departure and cancels them upon arrival;
- baggage handler:	helps passengers with their luggage upon request; there will be no checked baggage;
- janitor:	for spot cleaning during the day and overall cleaning overnight.

The number of position of each type to be filled at each station is given in Table 5-12. The staff required has been evaluated on the following basis:

- the manager works during business hours and is replaced by a stationmaster at other times and during his vacation;
- there is a stationmaster and/or assistant stationmaster on duty at all times;
- the station is open for service from 6h00 to the arrival of the last train;

- a ticket agent can perform 32 transactions per hour;
- the number of ticket agents is progressively adapted to traffic volume.

Based on salary costs given in Table 5-11 and staff requirements shown in Table 5-12, the corresponding 1991 direct salary costs for station operation systemwide would be, in 1983 dollars, $5,26 M/year for all four stations.

Clerical and supervision costs do not need to be added as they are included above already. Based on experience of modern passenger railway services, a material cost of $0.80 per passenger at stations must be added, which amounts to $1,03 M/year systemwide for 1 282 500 annual passengers; it increases progressively after 1991.

5.9.4 Reservation Personnel

Reservations would be handled from a central facility located either in Montreal or at the system control center in Deux-Montagnes, using Zenith and INWATS numbers as required.

Each reservation operator would be equipped, like a station ticket agent, with a video-display-equipped intelligent on-line terminal linked to the central reservation data base. Reservation personnel requirements were computed on the basis of a productivity level equivalent to two clerk-minutes per passenger.

Based on a total annual traffic of 1 282 500 in 1991, 2,56 M clerk-minutes would be required, equivalent to 42 733 annual clerk-hours. Based on a productivity of 1 664 h/year, 26 clerks would be required.

Table 5-12

Station Operation Personnel for Rail

Position	Schedule	Station								Total Staff
		Montreal		West Island		Mirabel		Ottawa		
		Positions	Staff	Positions	Staff	Positions	Staff	Positions	Staff	
Station manager	9 - 5 weekdays	1	1	1	1	1	1	1	1	4
Clerical Personnel	9 - 5 weekdays	2	2	1	1	1	1	2	2	6
Station Master	At least one on duty 24 h / day 365 days / year	1	4	1	4	1	4	1	4	16
Assistant Sta. Master		1	4	1	4	1	4	1	4	16
Ticket Agents (Peak period requirements) 1991	Stations open: 20 h / day 365 days / year Variable staff through day Productivity: 1664 h/ person/year	6	18	3	9	2	6	7	21	54
1996		7	22	4	11	2	7	8	25	65
2001		9	26	4	13	3	9	10	30	78
2006		9	27	4	14	3	9	11	32	82
2011		9	27	5	14	3	9	11	32	83
Ticket Taker	20 h / day	1	4	1	4	1	4	1	4	16
Baggage Handler	20 h / day	1	4	1	4	1	4	1	4	16
Janitor	20 h / day	2	8	1	4	1	4	2	8	24
Total (Peak Period) 1991	-	15	45	10	31	9	28	16	48	152
1996	-	16	49	11	33	9	29	17	52	163
2001	-	18	53	11	35	10	31	19	57	176
2006	-	18	54	11	36	10	31	20	57	180
2011	-	18	55	12	36	10	31	20	59	181

At an average annual salary cost $31 000 per agent, according to Table 5-11, this implies a system salary cost of $0,81 M for reservations, to which 4% must be added for clerical work and 14% for supervision, for a total cost of $0,93 M/year in 1983 dollars.

5.9.5 System Operation Personnel

System operation personnel is essentially involved in supervising train operation, chiefly from the control centre but also, to a limited extent, from terminals.

To accomplish these functions, the following positions must be filled:

- manager: has the executive authority for managing all functions related to train operation; he is assisted by support staff for administrative tasks;
- dispatcher: has the ultimate authority for the day-to-day operation of the system within established policies and procedures;
- assistant dispatcher: assists and replaces the dispatcher and performs specific functions related to the rotation of rolling stock through maintenance cycles and the administration of passenger information services;
- signal operator: is continuously involved in monitoring the signals and taking the necessary actions according to plans and procedures;
- electrical operator: is continuously involved in monitoring the power supply and distribution functions and taking the necessary actions;

Table 5-13

System Operation Personnel for Rail

Position	Schedule	Base								Total Staff
		Montreal		Control Center		Mirabel		Ottawa		
		Positions	Staff	Positions	Staff	Positions	Staff	Positions	Staff	
Manager	9 - 5 weekdays	-	-	1	1	-	-	-	-	1
Clerical Personnel	9 - 5 weekdays	-	-	2	2	-	-	-	-	2
Dispatcher	24 h / day 365 days / year	-	-	1	5	-	-	-	-	5
Assistant Dispatcher	24 h / day 365 days / year	-	-	1	5	-	-	-	-	5
Signal Operator	24 h / day 365 days / year	-	-	1	5	-	-	-	-	5
Electrical Operator	24 h / day 365 days / year	-	-	1	5	-	-	-	-	5
Terminal Supervisor	24 h / day 365 days / year	1	5	-	-	1	5	1	5	15
TOTAL	-	1	5	7	23	1	5	1	5	38

- terminal supervisor: has on-line authority over all on-board staff staff based at his terminal, there is a terminal supervisor in Montreal, in Ottawa, and also in Mirabel on account of engineman changes.

The total number of positions of each type to be filled at the control centre is shown in Table 5-13. The staff required has been evaluated on the following basis:

- the manager works during business hours and is replaced by the dispatcher in charge at other times,
- there is a group of four persons on duty in the control center at all times: dispatcher, assistant, signal and electrical operators;
- there is a terminal supervisor on duty 22/h day.

Based on Table 5-11, the following average annual salary costs are assumed: $52 000 for the System Operation Manager, $43 000 for a Terminal Supervisor, $36 000 for a Dispatcher, $31 000 for an Assistant Dispatcher or Operator, $26 000 for clerical personnel.

On that basis, the 1991 salary costs for system operation would be $1,39 M/year, which includes clerical and supervision. Material costs are included in the signal system maintenance.

5.9.6 Rail Operating Costs

They are given in Table 5-14.

Table 5-14

Breakdown of 1991 Operating Costs for Rail
(in 1983 Dollars)

Position	Staff	Direct Salaries ($M)	Indirect Salaries ($M)	Total ($M)
Enginemen	42	2,35	0,42	2,77
Conductors	25	1,30	0,23	1,53
Stewards	100	2,60	0,47	3,07
Train Operation Salaries				7,37
Material Costs for Train Operation (10%)				0,74
Total Costs for Train Operation				8,11
Station Manager	4	0,22	0,16	0,38
Station Masters	16	0,83	-	0,83
Assistant Station Masters	16	0,64	-	0,64
Station Personnel	110	3,41	-	3,41
Station Operation Salary Costs				5,26
Material Costs for Station Operation ($0.80 per passenger)				1,03
Total Costs for Station Operation				6,29
Reservation Agents	26	0,81	0,15	0,96
Salary Costs for Reservation				0,96
Material Costs: Included in Station Operation				-
Total Costs for Reservation				0,96
System Operation Manager	1	0,05	0,05	0,10
Terminal Supervisors	15	0,65	-	0,65
Dispatchers	5	0,18	-	0,18
Operators & Ass't Dispatchers	15	0,46	-	0,46
Total				1,39
TOTAL OPERATING COST				16,75
GENERAL AND ADMINISTRATIVE (8%)				1,34
TOTAL (CDN $M/year, 1983)				18,09

5.10 Maintenance Procedures, Personnel, and Costs

5.10.1 Rolling Stock

This is a major cost item and it is difficult to estimate, since the specific characteristics of the rolling stock to be maintained are not known, only its performance.

Fortunately, it is possible to proceed by comparison, and even with a surprising degree of accuracy. A study recently performed by Sofrerail for VIA (12) has shown that the French and Canadian procedures for maintaining rolling stock are remarkably similar, to the point of using identical tools, equipment, and procedures. To complement this technical comparison, it was found that Canadian salary and material costs are almost systematically 20% higher than corresponding French costs.

The same report also provides very detailed statistical costs for maintaining rolling stock used exclusively in high speed passenger service at 200 km/h. Since this cost information is so detailed, they can be readily adapted to the expected configuration of the Rail system used in this study.

Based on this, the 1982 French maintenance cost for a 4-car electric self-propelled consist would be in the order of 9,7 FF/train-km. Adapting to Canadian conditions (20% increase in cost), and updating to 1983 (material and salary increases of 10%), the unit cost would be $2.33/train-km for a four-car train.

Each train in service makes three round trips daily for a total of 1 140 km. As six trains are in service, the fleet travels 6840 revenue km per day, 2,496 M revenue km per year. Adding 7% for dead-end travel, the fleet covers 2,67 M km per year. As the fleet consist of 9 trains that rotate through maintenance cycles, each train travels, on the average 296 800 km per year.

Based on the above unit cost of $2.33/train-km, the total annual cost for rolling stock maintenance is estimated at $6,22 M/year.

Presuming that 55% of this amount is labour costs over which 14% supervision applies, the direct labour cost would be $3,00 M/year. As the VIA 1983 average salary cost at VIA is $29 000 per person, this amount implies a direct labour force of 104 persons, out of which 40 would work on overhaul in a workshop and 64 on regular maintenance and cleaning at one or two depots (logically located at or near terminals).

Japanese National Railways also conducted an operation and maintenance cost study for VIA (13). Applying the method described in that study, the annual cost of rolling stock maintenance for the Rail system is estimated at $6,76 M. This second estimate, which uses a totally different approach, is within 9% of the first.

5.10.2 Track and Structures

Three types of tasks must be performed to ensure a high degree of serviceability for track and structures:

- regular inspection of track and structures, including snow removal and local repair of light damage;
- periodic replacement of track components;
- in-depth track analysis using specialized equipment.

Regular inspection of track and structures will be effected by the system's own forces. For this purpose, the route will be broken down in four sections, each covering a territory of 45 km in length approximately.

Each section gang will consist of 9 trackmen and one foreman, there will be two supervisors and one manager with clerical staff, for a total annual salary cost of $1,35 M; this is based, according to VIA practice, on $29 000 for trackmen and clerical personnel and $44 000 for supervisors and managers.

Each section gang is housed in a section building and has the following equipment available: a Hi-Railer vehicle with snow blower attachment, two light track vehicles and a fully-equipped truck used also as personnel carrier. Operating costs for this equipment and miscellaneous will raise the total annual cost of track and structure maintenance forces to $1,69 M. It can be presumed that 80% of this cost is for track maintenance, the rest for structures.

Programmed periodic replacement of track components will be as follows:

- replacement of rail in curves and grades (assumed 10% of route): every 5 years: $5,53M in years, 5, 10, 15, and 20, (10% of $42,7M plus $12,6M, from Table 5-2);
- replacement of ballast: 20% every 5 years;
- replacement of turnouts: every 7 years for high-speed and 15 years for others;

In addition, some track maintenance work should preferably be contracted out: track tamping, rail grinding, chemical spraying, etc. This should cost on the average $1 500 per single track-km per year: $0,63 M/year for the route.

Finally, there should be periodic ad hoc inspections for track status diagnosis, such as: track geometry, track circuits, track wave wear, catenary, rail status, etc. This would better be done by the railways or contractors, using specialized measuring equipment. This should cost $350 000 per year for the route.

Total track and structure maintenance costs should thus amount to $2,67 M/year, plus capital expenditures (component replacement could be considered as a capital expense for facilities rehabilitation, rather than as an operating expense).

5.10.3 Power System

The maintenance requirements for the power supply and distribution sub-systems were estimated and based on the GO Transit Electrification Study, which considered a Phase I route length of 250 km, similar to the 185 km Rail route. The maintenance team would be managed by an electrical traction engineer and would comprise two groups.

The Routine Maintenance and Inspection Group would consist of:

- 2 foremen ($36 000/year);
- 2 chargehands ($29 000/year);
- 2 electricians ($31 000/year);
- 3 linesmen ($29 000/year);
- 3 assistant linesmen ($29 000/year).

For emergency and major repairs, the above group would need to be augmented by 6 men with limited catenary training: these would normally be employed on other duties and are thus accounted for elsewhere.

The resources necessary to support such a maintenance organization would typically comprise:

- office, workshop, depot for the catenary inspection car and its locomotive: those would normally be integrated with other resources required by the system; the total area required for the above functions would be approximately 400 m^2;

- spare materials: normally 0,5% of the erected materials are kept as spares;
- transport vehicles: 2 three quarter ton road/rail trucks;
  1 personnel carrier;
  1 three ton truck;
  1 work train.

Salary costs, using the above data from Table 5-11, would amount to $0,54 M/year. Adding 14% for supervision and 4% for clerical would bring this to $0,64 M/year. Materials, supplies, and vehicle ownership and operating costs would amount to $0,10 M/year bringing the total power system cost maintenance to $0,74 M/year.

5.10.4 Signalling and Communications

The signal equipment will be designed for ease of maintenance. Computer and microprocessor parts will have hot standby backup, automatic switchover so that out-of-service time should be reduced to zero. Failures in the field will most likely occur where climatic conditions and over line stresses (vibrations) are severe. The on-board equipment is also subject to severe vibration and, although packaged to handle these stresses, historically this is where most failures occur.

Failures are expected to be few but, when they occur, it is critical to respond quickly. Therefore it is necessary for the force to be mobile and for the train not to be too far from the extremity of a signal maintenance territory.

The route length is approximately 185 km. A reasonable length of maintenance territory is 50 km. A two-man signal team should be planned on each territory during the first several years of operation: while equipment is being tested, modified, this is a reasonable expectation. Supervision from the control center is necessary and this position should be backed up with two skilled technicians initially and, depending on the performance of equipment and ability of the signal field forces, could be reduced at a later date.

Initially signal technicians could be required to ride the trains to help keep performance on time. They would be provided by the equipment supplier.

The cost of signal maintenance will be estimated using a salary cost of $31 000/year for technicians, $29 000/year for each of the 8 maintenance agents, plus 4% for clerical, 14% for supervision, and 20% for parts and supplies. The total annual cost for system maintenance would thus be $0,41 M/year (1983 dollars).

The initial staff is somewhat large. Since the operation must be successful (trains appear on time) and the operating staff will be newly trained (but unexperienced with the actual operation), it would be unwise to reduce the maintenance force to a lower level.

5.10.5 Stations, Buildings, and Facilities

Based on observed railway costs, the cost of maintaining stations and other buildings, along the line, including power supply sub-stations, should amount to $2000 per year per line-km: $0,4 M/year for the whole system.

The cost of maintaining the control center, storage areas, depots, and the workshop should amount to $1,5 M/year for the system.

5.10.6 Total Maintenance Cost

The total maintenance cost and its breakdown are given in Table 5-15.

Table 5-15

Maintenance Costs for Rail (1991)

System Element	Useful Life (Years)	Maintenance Factor (%)	Capital Cost ($M)	Annual Maintenance Cost ($M/year)
VEHICLES				
Sub-Total	20	6,6	94,5	6,22
INFRASTRUCTURE				
Roadbed	100	0,0	53,3	0,00
Track Foundation	50	0,2	69,1	0,15
Ballast	25	8,3	14,5	1,20
Track	40	0,4	97,8	0,43
Fence	20	1,3	15,5	0,20
High Speed Turnouts	20	2,8	10,7	0,30
Other Turnouts	40	1,4	3,6	0,05
Sub-Total	-	(0,9)	264,5	2,33
STRUCTURES				
Grade Separations	50	0,2	39,7	0,09
Special Structures	50	0,2	44,6	0,10
Bridges and Culverts	50	0,2	72,5	0,15
Sub-Total	-	(0,2)	156,8	0,34
POWER AND CONTROL				
Power Sup. & Distribution	40	1,8	42,2	0,78
Signalling	40	1,0	41,1	0,41
Communications	20	0,0	3,5	0,06
Sub-Total	-	(1,4)	87,8	1,15
FACILITIES				
Sub-Total	40	14,5	13,1	1,90
ADMINISTRATION (8%)	-	-	-	0,96
TOTAL (CDN $M 1983)	-	2,1	616,7	13,00

5.11 Power Consumption Costs

A precise evaluation of the amount of power consumed for vehicle propulsion would require an elaborate analysis of the expected train pattern and a computer simulation of train movements along the proposed route. The data for such analyses is not available, as the rolling stock is not identified: even if it were, within the scope of the present study, such a simulation using hypothetical data would be spurious. Fortunately, a precise evaluation is not warranted, as there are significant differences in power consumption costs between Rail and Maglev.

As a result of these considerations, it appears legitimate to use, for evaluating power consumption costs, a simplified formula similar to those used by VIA Rail in its Corridor planning analyses. Such formulas recognize two major components in the charges to be made by the Utility to the HSGT Operator: a demand-related charge based on the maximum monthly demand (this allows the Utility to recuperate the costs incurred for providing equipments to supply power to the system) and a consumption-related charge corresponding to the market value of the electrical energy effectively consumed for train propulsion. The following formulas provide reasonable approximations of these charges:

ACPD = 12 * MCP * ACPT * WPC * SEC * V * (S1 + S2)
ACEC = 365,25 * CKWH * ACPT * WPC * SEC * ADF * RD

where :
ACPD : annual charge for power demand ($/year);
12 : the number of months/year;
MCP : monthly charge for power demand ($6,66/kW/month);
ACPT : average number of cars per train (4 in 1991, Figure 5-1);
WPC : average loaded weight per car (69 t, Section E.2);
SEC : specific energy consumption (0,0046 kWh/tonne-km);

V : maximum speed (200 km/h),

S1 : total number of substations (3, Table 5-8);

S2 : number of substations feeding two trains during a peak period (2, from meet points in Figure 5-2);

ACEC : annual charge for energy consumption;

365,25: the number of (days/year);

CKWH : the unit charge for energy ($0,0157/kWh);

ADF : average daily frequency in departures per day in both directions (36/day in Figure 5-2);

RD : route distance (trains travel 190 km).

Based on the above formulas and the data given and referenced when explaining their symbols, the maximum monthly power demand for Rail will be 12,7 MW in 1991. The coresponding charges will be as follows:

Period	Cars/ Train	Annual charge for Power ($/year)		
		Demand	Energy	Total
1991-1998	4	$1,014 M	$0,511 M	$1,52 M
1999-2011	5	$1,267 M	$0,639 M	$1,91 M

The above amounts are in 1983 Canadian dollars

REFERENCES FOR CHAPTER 5

1. "Building the Joetsu Shinkansen", Railway Gazette International, 134, 5, May 1978, pp. 286-290.

2. Shin-Ichi Kingajukuro, "Renovating the Tokaido Shinkansen", Railway Gazette International, 134, 5, May 1978, pp. 299-300.

3. Georges Jacques Jann, "Track Approaching Perfection", Railway Gazette International, 137, 9, September 1981, p. 730.

4. P.F. Sullivan, "Rationale and Technology used by Amtrack to Select Concrete Ties for Use in the NEC", paper presented at the 62nd Transportation Research Board Meeting, Washington D.C., January 1983.

5. "SNCF - Beating the Squeeze on Track Maintenance Time", International Railway Journal, October 1982, pp. 29-33.

6. John W. Weber, "The Concrete Tie: Performance Round-up", Railway Track and Structures, August 1980, pp. 26-30.

7. "Les couches d'assise de la voie ferrée", Revue générale des chemins de fer, décembre 1978, pp. 773-796.

8. "Maintaining a 200 km/hr Regular-Internal Diesel Service", Railway Gazette International, Vol. 134, no. 3, March 1978, pp. 119-123.

9. "TGV - Maintenance Modifications", International Railway Journal, 22, 10, October 1982, p. 41.

10. "TGV - Maintaining the Fleet", Railway Gazette International, 137, 9, September 1981, pp. 738-739.

11. Direction de la construction, "Liste et prix des ouvrages d'infrastructures de transport", Ministère des Transports du Québec, Québec, updated regularly.

12. Sofrerail "Etude des coûts de maintenance et d'exploitation d'une desserte ferrovière rapide" for VIA Rail Canada, Paris, November 1982.

13. Japanese Railway Technology Corporation, "The Maintenance and Operation Cost of a High Speed Rail Service of the East and West Corridors of Canada", for Via Rail Canada, New York, January 1983.

6. MAGLEV SYSTEM DEFINITION AND COSTS

The objective of this chapter is to identify, describe, dimension, and enumerate all the components making up the Maglev system used for comparison in this study, and to present the estimation of its capital and operating costs.

The first section in this chapter presents the principles and assumptions used for defining the system; they are the same as for the Rail technology. These principles and assumptions are based on the traffic forecasts (Chapter 1) and performance specifications (Chapter 3) outlined previously. The second section in the chapter describes the method used for system definition and the design conditions on which that definition is based, as well as the principles and methods used for cost estimation.

The third section discusses the operational strategies used as a basis to define the required system capacity and adapt it over the years to the expected growth of traffic. The fourth section outlines the characteristics of the vehicle and explains how the size of the fleet required for operation was evaluated and its procurement cost estimated. The fifth section describes the infrastructure for the Maglev system: guideway layout, right-of-way acquisition, and site preparation.

The sixth section covers the guideway design and structure; the seventh, the guideway-mounted equipment, while the eighth discusses the stations; the ninth, the power supply equipment; and, the tenth, auxiliary equipment. The eleventh section describes the operating procedures and explains how they were used a basis for estimating the operating personnel requirements and costs; the twelfth provides an estimation of maintenance costs. The thirteenth section discusses power supply and energy consumption costs.

Many of these sections are complemented by a corresponding section in Appendix F, where detailed documentation will be found.

6.1 Basic Assumptions Underlying System definition

The comparative technology assessment being performed in the present study must above all identify the fundamental differences between the Rail and Maglev technologies.

To facilitate their identification, it was felt useful to resort to the concept of a "basic system", under the assumption that comparing two "basic" systems, with a minimum of contextual differences, should underscore the essential technological differences. Once these basic systems are defined are compared, each system can eventually be optimized so that its revised definition reflects its specific advantages and the specific requirements of the application.

To maintain a greater degree of objectivity, then, the same assumptions were used in defining the basic system for both technologies; this common basis and the use of similar definition procedures also helped avoid overdesign or underdesign in any of the two basic systems. Most of these fundamental assumptions are a direct reflection of the Performance Specification (Chapter 3); they will now be described briefly.

6.1.1 Geographic Coverage

Both systems will provide high speed service between the city centers of Ottawa and Montreal through Mirabel Airport. In Montreal, both systems will have their terminal in the very core of downtown, and a suburban station in the West Island. To avoid differential effects on ridership, this station will be very nearly in the same location for both systems. Both systems will have their Mirabel Station on the ground floor of the existing terminal building, and their Ottawa terminal at the existing VIA Station.

6.1.2 Routing

All trains will go from Montreal to Ottawa (or vice-versa) with two mandatory stops: one in Mirabel and one at their suburban station. No train will provide service beyond Montreal or Ottawa or skip the Mirabel Station or the suburban station. The actual route alignement is as described in Chapter 4.

6.1.3 Time Coverage

Service will be provided seven days a week, fifty-two weeks a year. The schedule will be such that the last train in the evening leaves approximately 18 hours after the first train in the morning has left.

6.1.4 Frequency of Service

The frequency of departures will be dictated by quality-of-service considerations, not by capacity requirements. The frequency will be such that there is, on a daily average, one departure per hour from each terminal. Departures will be more frequent early in the morning, around lunch time, at the end of the normal business day, and early in the evening for flight departures from Mirabel.

6.1.5 Capacity Strategy

Given a frequency fixed by service considerations, capacity will be increased by varying consist length. Train length will be such that the required capacity is offered, yet a realistic load factor is obtained. That might be 90% at peak hours and 30% off peak, with a daily average in the order of 55%.

6.1.6 Safety

Safety standards outlined in Table 3-1 imply automatic train protection and the elimination of all grade crossings.

6.2 Methodology for System Definition and Costing

6.2.1 Sub-system and Geographic Disaggregation

For definition and costing purposes, the basic Maglev system will be disaggregated along the following functional or physical sub-systems:

- capacity, schedules and consist length (Sections 6.3 and F.1);
- vehicles (Sections 6.4 and F.2);
- guideway layout, right-of-way acquisition, and site preparation (Sections 6.5 and F.3);
- guideway structure (Sections 6.6, F.4 and F.5);
- guideway-mounted equipment (Section 6.7);
- stations (Section 6.8 and F.6);
- power supply and distribution (Section 6.9);
- auxiliary and maintenance equipment (Section 6.10);
- operational procedures, personnel, and costs (Section 6.11);
- maintenance costs (Section 6.12);
- power costs (Section 6.13).

Whenever convenient, the sub-systems defined above were further disaggregated according to geography, as follows: Montreal downtown, Montreal Island, Laval, Mirabel, rural Ontario, Ottawa.

6.2.2 Design Conditions

The system design is based on the conditions prevailing in the year 1991, specifically, its capacity corresponds to a point midway between the expected minimum and maximum traffic in that year as given in Table 1-15. After 1991, capacity expansion would be achieved through consist length adjustment.

The basic Maglev system is designed to handle the expected traffic growth for 20 years after its service introduction in 1991. As an exponential decay of traffic growth is presumed from the year 2001 on, traffic growth would be null in 2011. If there was some growth at that time, the necessary system expansions would be justified based on that growth; this was not considered in the present study except in a sensitivity analysis.

6.2.3 Principles for Cost Estimation

The cost estimates are based on an evaluation of the materials and work necessary for the design, construction, testing and commissionning of the system defined in this chapter. The precision is limited by the level of detail to which that definition could effectively be conducted in the framework of the present study.

Unless otherwise noted, it is assumed, when estimating costs, that the work is done in Canada, by Canadian firms, according to Canadian business practices and principles, using conventional (but up-to-date) construction methods and/or manufacturing techniques. It is also presumed that few significant changes will occur as to prevailing conditions and constraints concerning institutions, salaries, and productivities.

In several instances, and especially for guideway construction, the sheer size of the work and/or its highly innovative nature would trigger the development of new construction methods. If they are to be used, these methods should offer noticeable savings in construction costs as compared to present methods. Due to their speculative nature, such potential savings have been ignored; they should be considered in a formal feasibility analysis.

Construction costs are based on the geographic subdivision of the project and the award of four major contracts, all allowing the contractor to hire sub-contractors for specialties; the four contracts would proceed simultaneously.

It is presumed that the responsible authority would provide the contractors with physical and institutional access to the sites and with the surveying benchmarks necessary for accurately locating the alignment.

The contract for vehicles would be awarded to a Canadian carbuilder, which would be responsible for manufacturing engineering, fabricating some mechanical elements of the vehicle, procuring all electrical, electronic, and specialty components, and assemblying and testing the vehicle. This presumes that the carbuilder would obtain a licence and technical assistance from TransRapid, who would also supply components.

6.2.4 Cost Estimation Methodology

In general, construction costs were estimated based on unit costs observed recently on similar contracts. Such costs are normally public in Canada. Specifically, some institutions, such as Ministère des Transports du Québec, regularly publish disaggregated cost data on the contracts they awarded recently, with details on specific conditions. Such sources were used, when calibrating unit costs for structures and for infrastructure.

Quantities were estimated as part of the definition of each subsystem. The results are presented in this chapter and details on the estimation of quantities are found in Appendix F.

6.3 Capacity Definition

To define system capacity for this technology comparison requires a discussion of operational strategies, to identify what methods are presumed to be used for progressively adapting system capacity to a growing traffic while maintaining a satisfactory load factor.

Given an operational framework, the capacity of a Maglev service can be adapted to traffic by increasing the length of each train while maintaining frequency constant and/or by increasing the number of trains in peak and/or off-peak periods.

In this case, it was presumed that the frequency of service was maintained constant during the period of analysis, so that the necessary capacity increase is obtained by lengthening each Maglev train by the addition of extra sections. That way, the system infrastructure and fixed equipment maintain a capacity reserve that could conceivably be used for introducing additional trains for a Montreal - Toronto service through Ottawa and Kingston, for instance. It also avoids introducing frequency-related bias in the technology comparison.

The evolution of traffic and capacity with time are shown in Figure 6-1. Explanations will be found in Section F.1.

Based on an analysis of the vehicle performance (Section F.2), travel time is estimated to be 45 minutes, including 90 s stops at each of the two intermediate stations and a 6% time reserve, while accepting speed restrictions through curves corresponding to a maximum lateral acceleration of 1,0 m/s^2, which is the comfort limit with a 12° superelevation, as well as a speed limit of 200 km/h in urban areas (Montreal, Laval and Ottawa).

The resulting train traffic pattern, illustrated in Figure 6-2, will apply from 1991 to 2011. Four Maglev consists will have to be operated to provide the service described in Section 6.1.

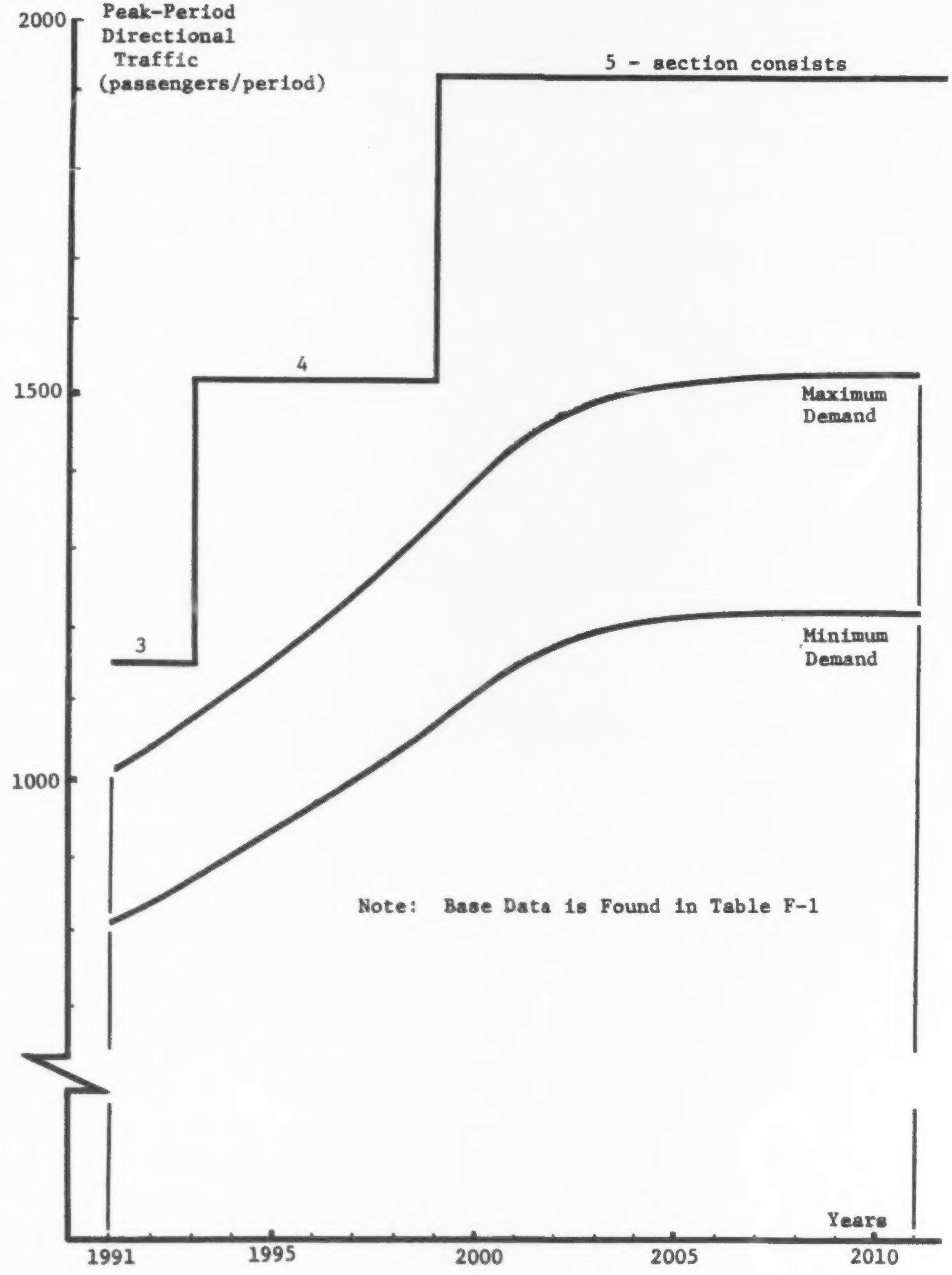


Figure 6-1 Traffic Growth and Capacity Adjustement for Maglev

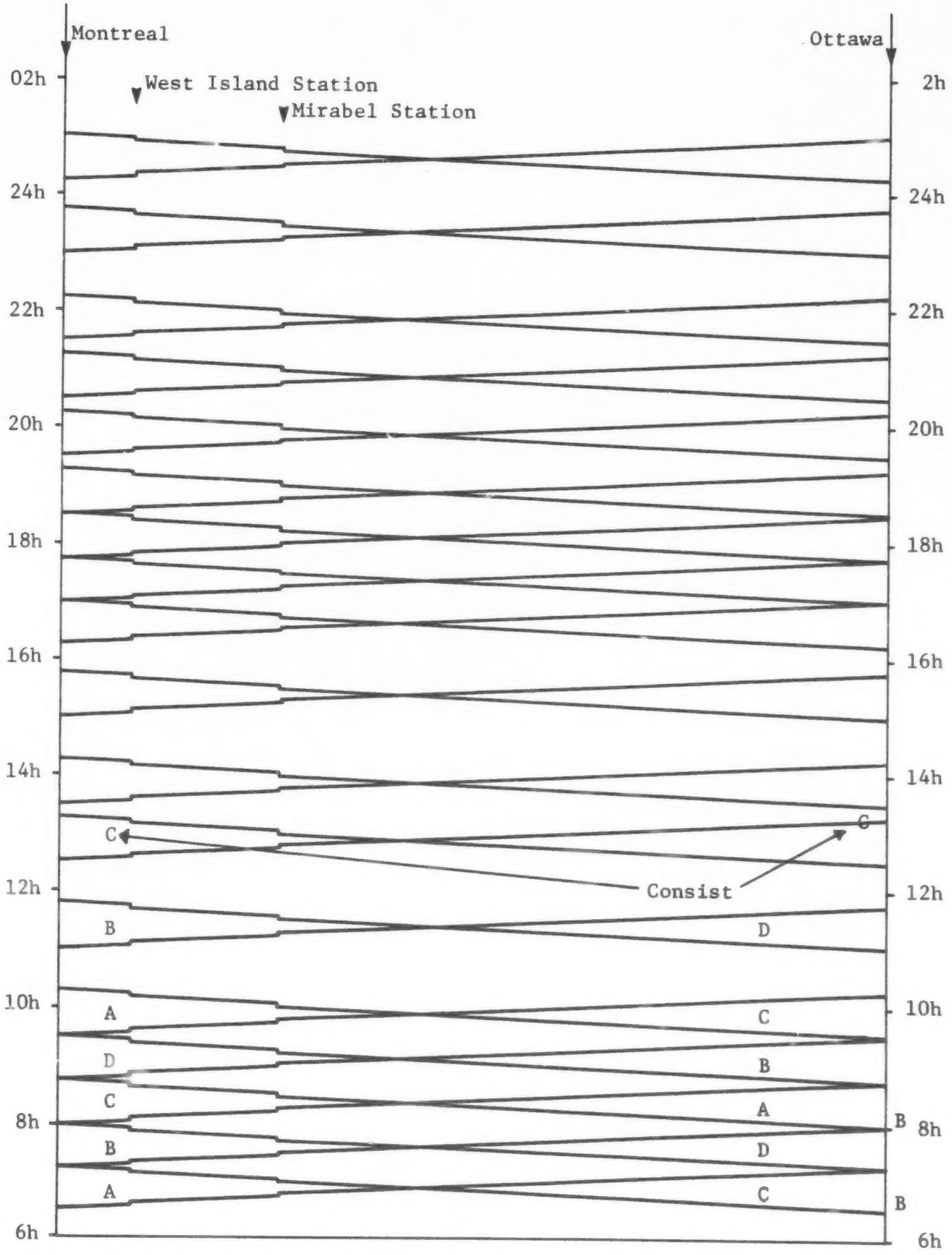


Figure 6-2 Train Traffic Pattern for Maglev

6.4 Vehicle

The basic Maglev consist is a bi-directional vehicle that is 54,2 m long, 3,7 m wide, and has an overall height of 4,2 m (Figure 6-3). As the bogies envelop the guideway, the top of the vehicle is only 3,2 m above the surface of the guideway. A cross-section of the vehicle on the guideway was shown in Figure 2-2.

Each vehicle is made of two identical sections and has a capacity of 192 seats with a 3 x 2 seat layout. Each section has four doors, two on each side. At each end, the driver's cockpit can be reached from the passager cabin. Under the cockpit is an aircraft-type sliding chute for emergency passenger evacuation.

The vehicle has a monocoque structure made up of sandwich plates (rigid polymer foam between two layers of aluminum) riveted onto transverse frames made of aluminum profiles. Each vehicle section is supported on four bogies which provide levitation, guidance, propulsion, and braking. The bogies are connected to the carbody with an air bag secondary suspension.

Each bogie carries eight levitation magnets; each magnet is 1,5 m long. They are placed horizontally along the longitudinal axis of the car, opposite the two-part linear motor stator, which is mounted on the underside of lateral projections of the guideway beam. Each bogie also carries six or eight guidance magnets, which are mounted vertically along the longitudinal axis of the vehicle, opposite guidance rails which are mounted vertically along the edges of the guideway beam. (Figure 6-4)

Propulsion is provided by a two-part iron-cored long-stator synchronous linear motor, mounted under the guideway and consisting of steel laminations intertwined with cable windings. No power collectors are used. The levitated vehicle is drawn by a traveling field wave generated by static converters located at each sub-station and fed into the stator windings.

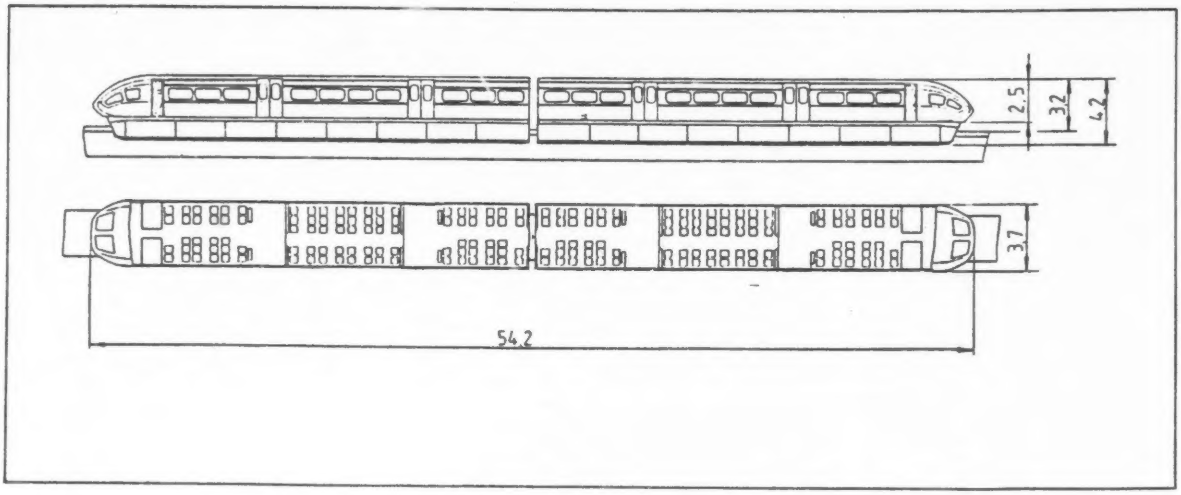
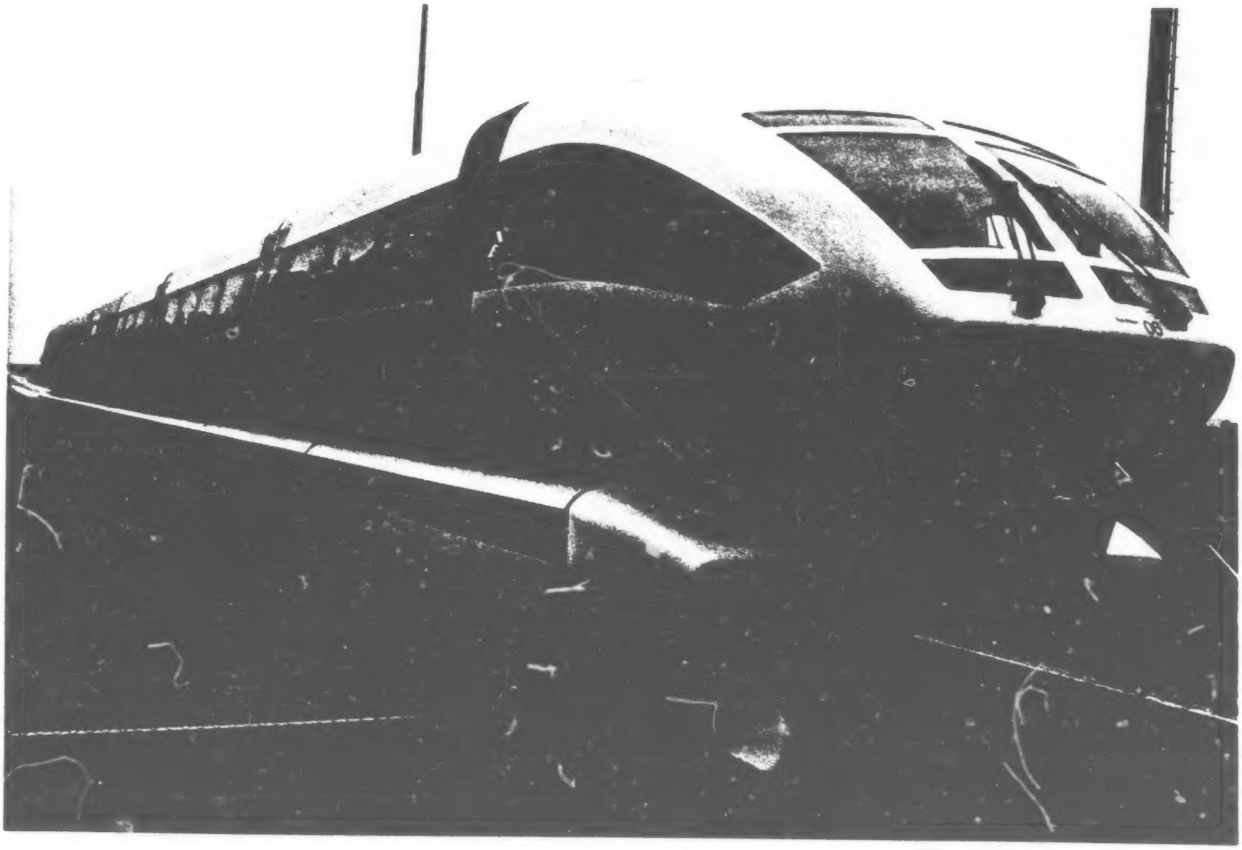

2.5
3.2
4.2
3.7
54.2

Figure 6-3 Maglev Vehicle: General View and Main Dimensions



The number of vehicle sections required was estimated as follows

Based on the travel time and schedule envisioned, four Maglev consists will be needed for operation, as seen in Figure 6-2. To offer the capacity shown in Figure 6-1, each train will initially consist of three end sections. To provide the additional capacity needed from 1993 on, one, intermediate section will eventually be added to each train, and later, a fifth.

In addition to the four trainsets used (two of which will lay overnight at each terminal), one more consist will be kept in standby at the shop (which will probably be located near Mirabel). This standby train will be kept as an operational reserve, ready to be dispatched to one or the other terminal should a Maglev consist normally used for operation become disabled.

Each Maglev consist will be sent periodically to the shop for preventative maintenance, as a unit. Based on experience with aircraft and with high technology trains such as TGV, each consist would be taken out of service for an assumed period of 40 days per year after teething problems are ironed out: it would thus be unavailable 11% of the time. Accordingly, a sixth train will be purchased, providing a 16% reserve for maintenance. This is in excess of expected requirements, but it will be a most welcome reserve until the whole fleet is fully debugged.

The cost of an individual vehicle was estimated as follows.

A basic cost estimate has been prepared by TransRapid International for the case of a series production of 100 sections for 2-section vehicles. This estimate is based on the experience gained while building a prototype vehicle for the Emsland test facility, and taking into account expected cost reductions due to production rationalization associated with series manufacturing; it will have to be modified to adapt to the present case as explained below.

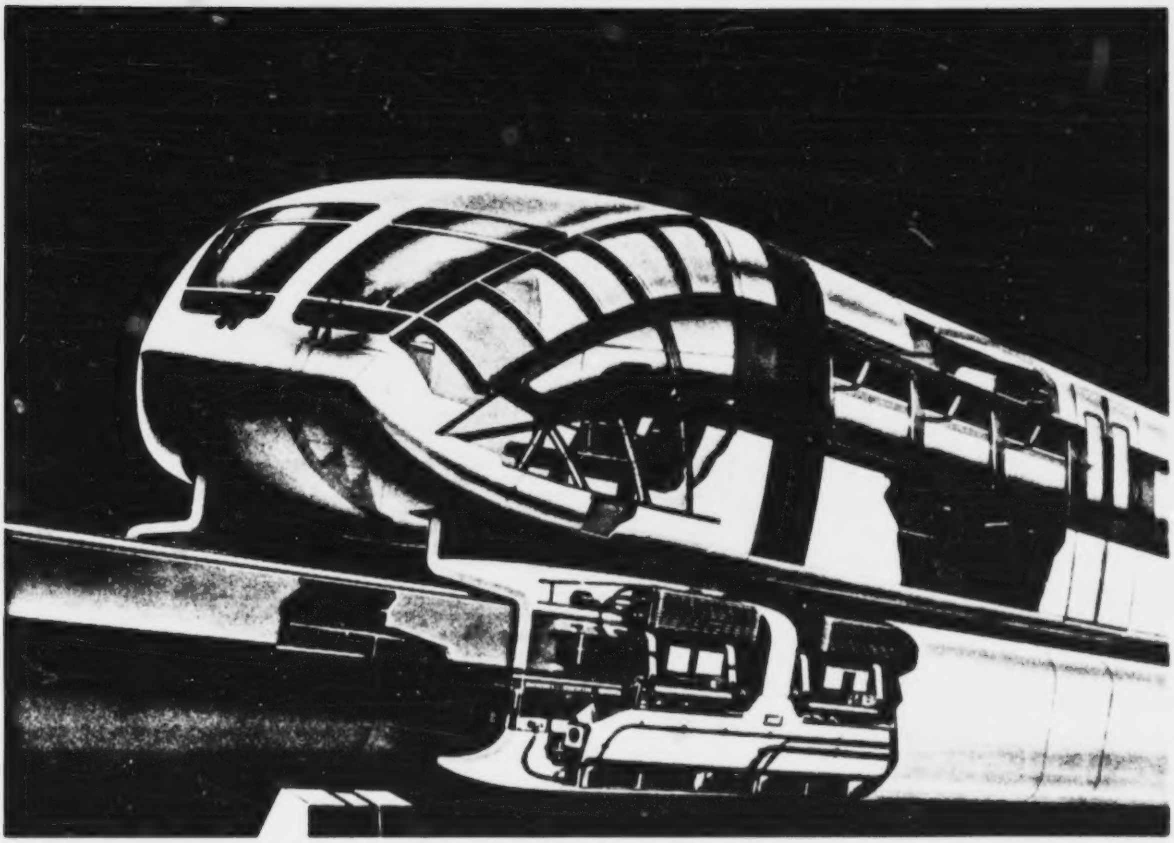


Figure 6-4 Levitation, Guidance and Propulsion Equipments on the Maglev Vehicle

The base estimate (at 2,15 DM/CDN$), is $10,7 M per vehicle, its breakdown is given in Table 6-1. As an intermediate section is not equipped for independent operation and lacks the on-board control and information system, its cost can be deducted from Table 6-1 to be $5,09 M ($10,18M for two sections).

As the above unit vehicle costs apply to an order for 100 sections, they must be adjusted as the Maglev system envisioned here will require only 18 sections in 1991, plus 6 intermediate sections to be placed in service in 1993, and six more in 1999, as explained above.

If one presumes that the effect of order size on costs is the same here as for transit cars, then reducing an order from 100 to 30 (if the whole fleet is considered as a single order) would increase the cost as follows: 6% for control equipment, 8% for propulsion, 12% for car body.

Applying these factors and spreading design costs over a shorter series, the cost for two end sections climbs to $12,0 M and that for two intermediate sections to $11,4 M.

Finally, the total cost of the fleet was estimated as follows.

The direct cost for the fleet, in CDN$ 1983, should be $106,2 M for the 18 sections (12 end, 6 intermediate) needed in 1991, $34,2 M for the 6 intermediate sections needed in 1993, and $34,2 M for the 6 intermediate sections needed in 1999.

Considering a 5% provision for spares, the total investment costs for vehicles for system opening in 1991 would amount to $111,5 M.

Table 6-1

Breakdown of the Maglev Vehicle Cost

Item	Material	Labour	Total	%
Carbody and Equipment Manufacturing of Aluminum frame construction, sandwich panels, purchase of interior finish components, windows and doors, seats, air conditioning unit, emergency slides.	$ 0,70 M	$ 1,30 M	$ 2,00 M	19
Levitation and Guidance System Magnetic bogies, magnets and their controls, power supply, sensors, choppers, linear generators, buffer batteries, charging equipment, cables and signalling, secondary suspension, mechanical brakes.	$ 2,69 M	$ 2,69 M	$ 5,38 M	51
On-Board Control and Information System Cockpit, terminals, processor, telecommand unit, communication and safety system	$ 0,35 M	$ 0,17 M	$ 0,52 M	5
On-Board Electrical Network Network and controls for powering auxiliairies using energy from linear generators or batteries; (these are accounted for above)	$ 0,52 M	$ 0,06 M	$ 0,58 M	5
Vehicle Integration Assembly of carbody, bogies, their equipment	$ 0,00 M	$ 1,76 M	$ 1,76 M	16
Design, Testing, Project Management	$ 0,00 M	$ 0,46 M	$ 0,46 M	4
TOTAL	$ 4,26 M	$ 6,44 M	$10,70 M	100

6.5 Infrastructure

This section describes the following aspects of the Maglev system:

- guideway layout, which results from operational strategies;
- right-of-way requirements, which result from the guideway layout, topography, and land use along the route;
- building relocations;
- site preparation;
- infrastructure costs.

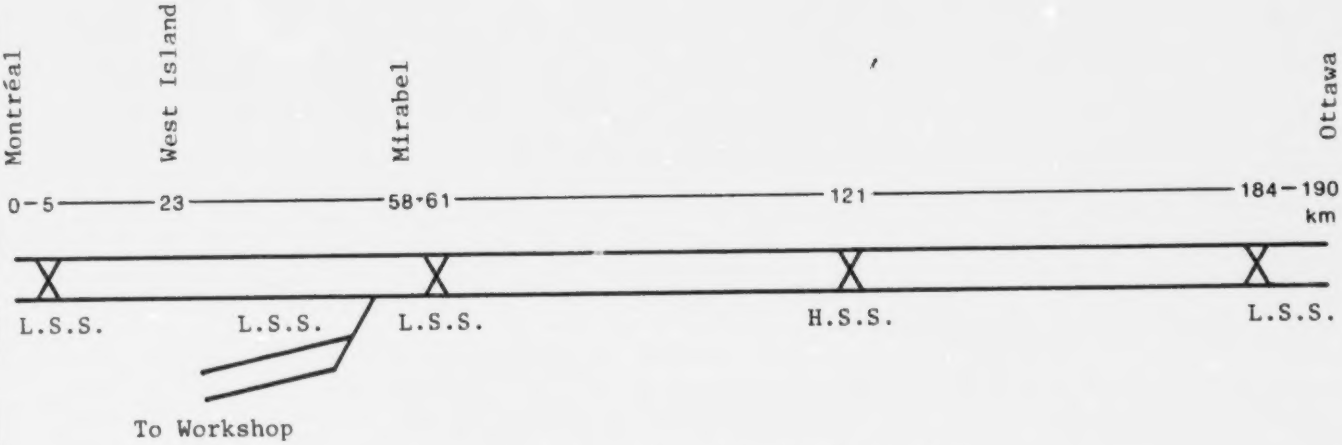
6.5.1 Guideway Layout

The Maglev system will be operated on a double guideway all the way from Montreal to Ottawa.

To increase operational flexibility and permit bi-directional movement on one guideway when the other is disabled, double crossovers will be installed at the following kilometric points: 5, 61, 121,194. The corresponding guideway schematic is shown in Figure 6-5.

6.5.2 Right-of-Way Requirements, Acquisition, and Rental

Wherever the guideway is built on or over an existing railway right-of-way (as from km 0 to km 17+600, from km 21 to 23, and from km 180 to km 189+500), air rights will have to be leased from the railways. It will be presumed that air rights have the same value as land (since the railways could want to develop them) and that the leasing formula used for Rail (Sub-section 5.5.2) is applicable to Maglev.


Montréal
West Island
Mirabel
Ottawa
0-5
23
58-61
121
184-190
km
L.S.S.
L.S.S.
L.S.S.
H.S.S.
L.S.S.
To Workshop

L.S.S.: Low Speed Switch
H.S.S.: High Speed Switch

Figure 6-5 Summary Guideway Schematic for Maglev

Whenever the Maglev guideway is built at grade, the necessary right-of-way will have to be purchased outright at prevailing land value. Normally, land would be acquired by expropriation to constitute a continuous right-of-way. With an average width of 10 m, including space for an unpaved emergency road of 6 m in width, the area required is estimated at 1000 ha.

When the Maglev guideway is built above ground on a new right-of-way, it could be argued that only the area required for the footings would need to be acquired from the present landowners, in addition to a right to trespass for guideway maintenance. The price to be paid for that trespassing right might be calculated by a similar formula as that used for leasing railway property: an annual rental equal to the land value times an interest rate 0,5% above the prime rate. There are no known precedents for the implementation of a long overhead guideway in a rural area, so the approach suggested above is speculative and will remain so as long as a typical case is settled in Court. Apparently, a similar compromise was reached for the Aerotrain test track in France years ago.

The land required for the Maglev right-of-way amounts to 493,5 ha as seen in Table 6-2. Of this area, 8,4% is over railways and air rights would be leased; another 15,2% is Federal land on the operational area of Mirabel Airport. Finally, the remaining 76,6% consists of private land to be acquired by purchase or expropriation. This land acquisition also involves the relocation or demolition of 53 buildings, mostly single-family houses; this is discussed in Sub- Section 6.5.3. Private land acquisition would be mainly in rural areas (91,1%) and to a much lesser extent in suburban areas (6,4%, chiefly in Laval) and in urban areas (2,5%).

Table 6-2

Right-of-Way Requirements for the Maglev Route

Acquisition Policy and Present Status	Further Classification	Context	System Requirements		
			Width (m)	Length (km)	Area (ha)
Rental of Air Rights over Railways	By Location	Urban	15	23,6	35,4
		Rural	15	4,0	6,0
		Total	-	27,6	41,4
	By Present Ownership	CN-owned	15	2,1	3,15
		CP-owned	15	25,5	38,25
		Total	-	27,6	41,4
Outright Acquisition of Land in Private Ownership	By Location and Width	Urban	15	6,4	9,6
		Suburban	15	16,0	24,0
		Federal (Mirabel)	30	25,0	75,0
		Rural	30	114,5	343,5
		Total	-	161,9	452,1
	By Present Land Use	Woodland	Variable	48,5	140,8
		Farm/Undeveloped	Variable	113,4	236,3
		Federal	Variable	-	75,0
		Total	-	161,9	452,1
All	Any	Any	-	189,5	493,5

Note: The right-of-way width is 30 m in rural areas to leave room for an emergency access road which is not needed in urban areas due to the availability of other means of access to the guideway such as cross streets.

A total of 9,6 ha of urban land must be acquired near Autoroute 13, where the West Island station will be, and also near Dorval Airport. Surrounding residential land was evaluated at $1.20/s.f. in 1980. As all land acquired will not necessarily be suitable for residential use, an average value of $1.00/s.f. will be assumed; that is $107 600/ha. The corresponding total land acquisition cost is estimated at $1,0 M.

A total of 16,0 ha of suburban land, chiefly in Laval, is required. Most of that land is agricultural and, due to recent legislation, can not be converted to other uses. Acquisition of that land would cause serious difficulties, as it would be a test of this legislation. The elevated guideway, however, presents significant advantages in this respect. A land value of $1.00/s.f., or $107 600/ha, will be assumed, as this is prime agricultural land. The acquisition cost is estimated at $2,6 M.

Based on information on recent sales of agricultural land in the rural areas concerned, a value of $2 000/ha appears representative. As an area of 343,5 ha must be acquired, the cost will be $0,7 M.

It will be presumed that there is no charge for the 75 ha of federal land. If there was a charge, at $2 000/ha, it would amount to $0,15 M; the value, however, could be higher than for rural land.

When the guideway is built above a railway, air rights can be presumed to be acquired by leasing, at an annual rental equal to the land value, times 0,5% above the prime rate: 10% will be assumed. It can be presumed that, as explained for the Rail system (Sub-section 5.5.2), the following values for industrial land apply:

Distance from centre	Land Value
0 km	$ 150.00/s.f.
5 km	$ 25.23/s.f.
5 km	$ 25.23/s.f.
10 km	$ 4.24/s.f.
15 km	$ 0.50/s.f.
20 km	$ 0.12/s.f.

Based on these values, the first 5 km along the CP right-of-way in Montreal, for a width of 15 m (7,5 ha), would be valued at $57,1 M and the rental would be $5,7 M/year.

For the next 5 km in Montreal and for the 4 km in urban area in Ottawa (which is over 5 km from the city centre), the average value is $11.89/s.f., the area is 13,5 ha, the total value is $17,3 M and the rental is $1,7 M/year.

From km 10 to 15 along the CP right-of-way, the average value is $2.37/s.f., the area is 7,5 ha, the total value is $1,9 M and the rental is $0,2 M./year

Finally, there is an additional 6,9 ha located partly on the CP (3,75) and partly on the CN (3,15) that, at an average value of $0.50/s.f., will be worth $0,37 M and rent for $0,04 M/year.

In total, right-of-way leasing costs would amount to $7,64 M/year.

6.5.3 Building Relocation

As a right-of-way for Maglev is being acquired, it will be necessary to relocate or demolish a certain number of residential and institutional buildings.

This was inventoried as part of the definition of the route, as it was an objective to minimize these relocations. The details of the inventory are found in Appendix C and are summarized below:

Area	Map	Expropriations
Dorval	C-3	2 Apartment Houses 1 Elementary School 4 single Family Houses
Laval	C-4	18 single Family Houses
Lachute	C-6	5 single Family Houses
Hawkesbury	C-7	14 single Family Houses
Plantagenent	C-9	5 single Family Houses
Hammond	C-10	4 single Family Houses

In total, one school, two apartment buildings (20 units each) and 50 single family houses must be demolished or relocated. The following unit prices were assumed: $1,0 M for the school, $500 000 each for the buildings, and $100 000 each for the houses.

On that basis the total cost of building relocation is estimated at $7,0 M.

6.5.4 Site Preparation

Site preparation consists of two activities: clearing woodland from the right-of-way and building an access road for construction. In rural areas, the access road will eventually be used as an emergency road for evacuating passengers from a stranded Maglev vehicle in case of a major power breakdown.

Woodland must be cleared along 50,55 km of the proposed route. For a right-of-way width of 30 m, the corresponding area is 14 655 ha. The unit cost of wood clearing, according to a construction cost handbook

Table 6-3

Capital Costs for Maglev Infrastructure

Item (Reference in Text)	Quantity (Unit Specified)	Unit Cost (as Specified)	Total Cost (CDN $ M, 1983)
RIGHT-OF-WAY ACQUISITION			
Rural Land	343,5 ha	$ 2 000 / ha	$ 0,7 M
Suburban Land	16,0 ha	$107 600 / ha	$ 2,6 M
Urban Land	6,4 ha	$107 600 / ha	$ 1,0 M
Federal Land	25,0 ha	$ 0 / ha	$ 0 M
Contingencies (20%)			$ 0,9 M
			$ 5,2 M
BUILDING RELOCATIONS			
Schools	1 u.	$ 1,0 M	$ 1,0 M
Apartment buildings	2 u.	$ 0,5 M	$ 1,0 M
Houses	50 u.	$ 0,1 M	$ 5,0 M
Sub-Total			$ 7,0 M
SITE PREPARATION			
Wood clearing	14 655 ha	$ 10 300 / ha	0,6 M
Access Road	156 km	$100 000 / km	$ 15,6 M
Contingencies (20%)			$ 3,2 M
Sub-Total			$ 19,4 M
TOTAL CAPITAL COSTS			$ 31,6 M

is $3 791/acre in 1982 on the average in the U.S.A. Applying the necessary correction factors (1.2 for Canadian dollars, 0,89 for geographic index, 10% for 1983), the cost amounts to $10 300/ha. The total cost is then $1,51 M.

Construction of a construction access road to be converted in an unpaved but well-graded emergency road is estimated to cost $10 000/km. Such a road is required along 156 km of the guideway, for a total cost of $15,6 M.

6.5.5 Infrastructure Costs

Capital Costs for the Maglev infrastructure are shown in Table 6-3.

In addition to capital costs, recurring costs must be incurred to lease air rights from the Railways. These will amount to $7,6 M. Details were given in Sub-section 6.5.1.

6.6 Guideway Design, Structure, and Costs

Physically and financially, the guideway is the most important element of the Maglev system.

6.6.1 Structural Requirements for the Guideway

Given the stringent tolerances required for the efficient operation of the magnetic levitation process, a rigid structure is necessary to support the vehicles.

To obtain the necessary rigidity, the surface over which the vehicles glide is designed to consist of a continuous succession of beams or girders. These can be made of steel or prestressed concrete, depending on the availability and market prices of these materials.

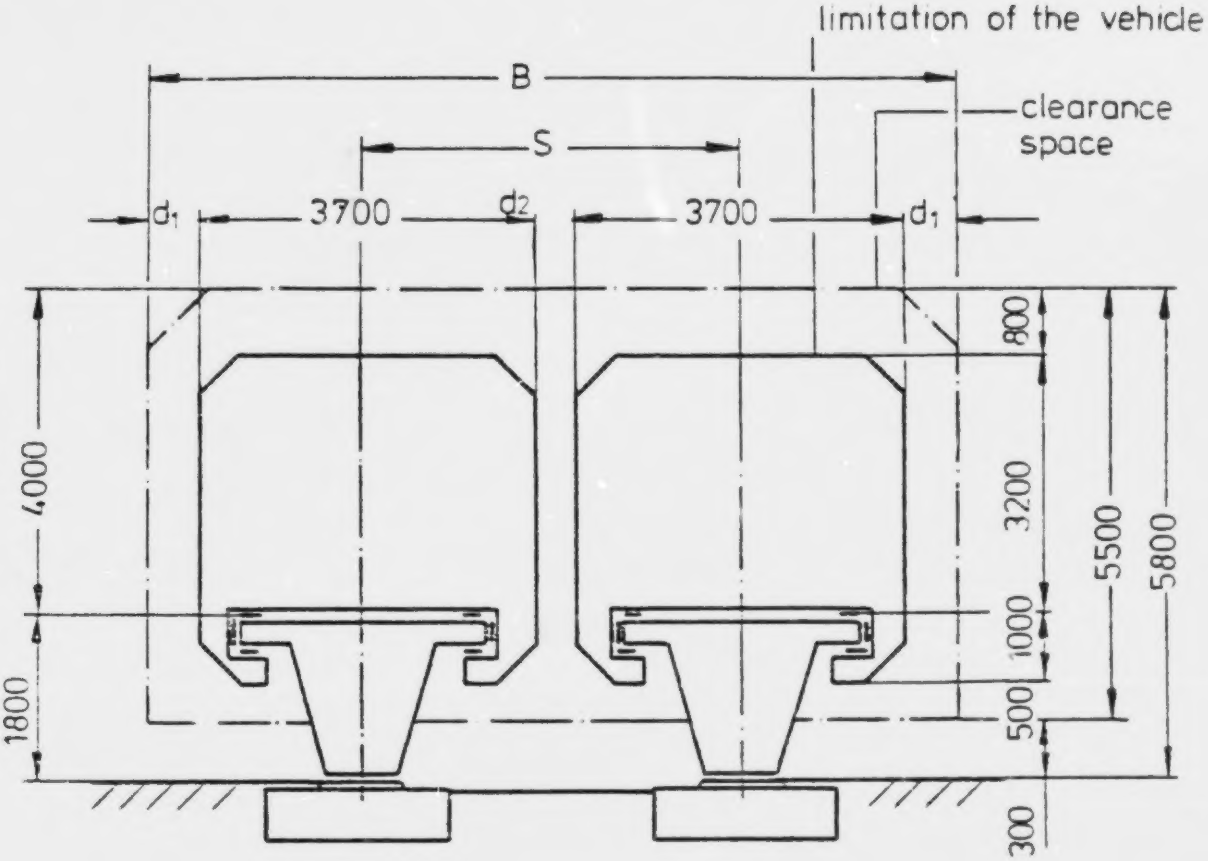
The guideway beams bear all the equipments required for power distribution, and propulsion, levitation and guidance of the vehicles; these equipments, which are equivalent to the wayside substations, catenary, and track in a railway system, are discussed in Section 6.7.

6.6.2 Description of Structural Elements

The Maglev guideway consists of four elements, some of which may be present only in an elevated guideway:

- beams, which bear the stator, levitation and guidance rails, and signalling system; beams. Beams are always needed; they are discussed in Sub-section 6.6.4;

- bearings, which provide the necessary adjustment to ensure the desired guideway geometry even in case of differential settlement between foundation elements. Bearings, which are also always needed, are discussed in Sub-section 6.6.5;


limitation of the vehicle
B
clearance space
S
d1
3700
d2
3700
d1
800
3200
1000
500
300
5500
5800
4000
1800

	v[km/h]		
	200	300	400
B[m]	9.10	9.70	11.80
S[m]	4.20	4.40	5.10
d_1[m]	0.60	0.80	1.50
d_2[m]	0.50	0.70	1.40

Figure 6-6 At-Grade Guideway on Footings

- piers or columns, which provide the desired clearance between the terrain (or an obstacle) and the underside of the guideway beam. Piers or columns are used only for an elevated guideway; they are discussed Sub-section 6.6.6;

- foundation elements, which transmit to the ground the live and dead loads associated with the vehicles and guideway beams and bearings. Foundation elements are always needed, but they vary significantly in size and design with the guideway clearance and the nature of the sub-soil; they are discussed in Sub-section 6.6.7.

6.6.3 Guideway Configuration for the Application

Depending on the configuration selected, the guideway beams and bearings can be supported:

- on slabs or pads, when the guideway is at grade (Figure 6-6);
- on columns if the guideway is straight and built on good soil;
- on piers if the guideway is curving or built on poor soil (Figure 6-8);

From a brief analysis of Figures 6-6 and 6-8, it is apparent that the cost of the guideway and the nature of its structural elements (except for the beam) change significantly with the configuration adopted.

Before evaluating construction costs, it becomes necessary to determine whether the Maglev guideway considered in this study should be built at grade, elevated, or in a tunnel. A priori, tunnel construction was withdrawn from further consideration on account of its excessive costs.

No suitable right-of-way is available for at grade routing in urban areas near Montreal, as discussed in Appendix C. Hence, the guideway will have to be built as an elevated structure in Montreal and Laval. At grade construction is possible near Ottawa Terminal, as railway

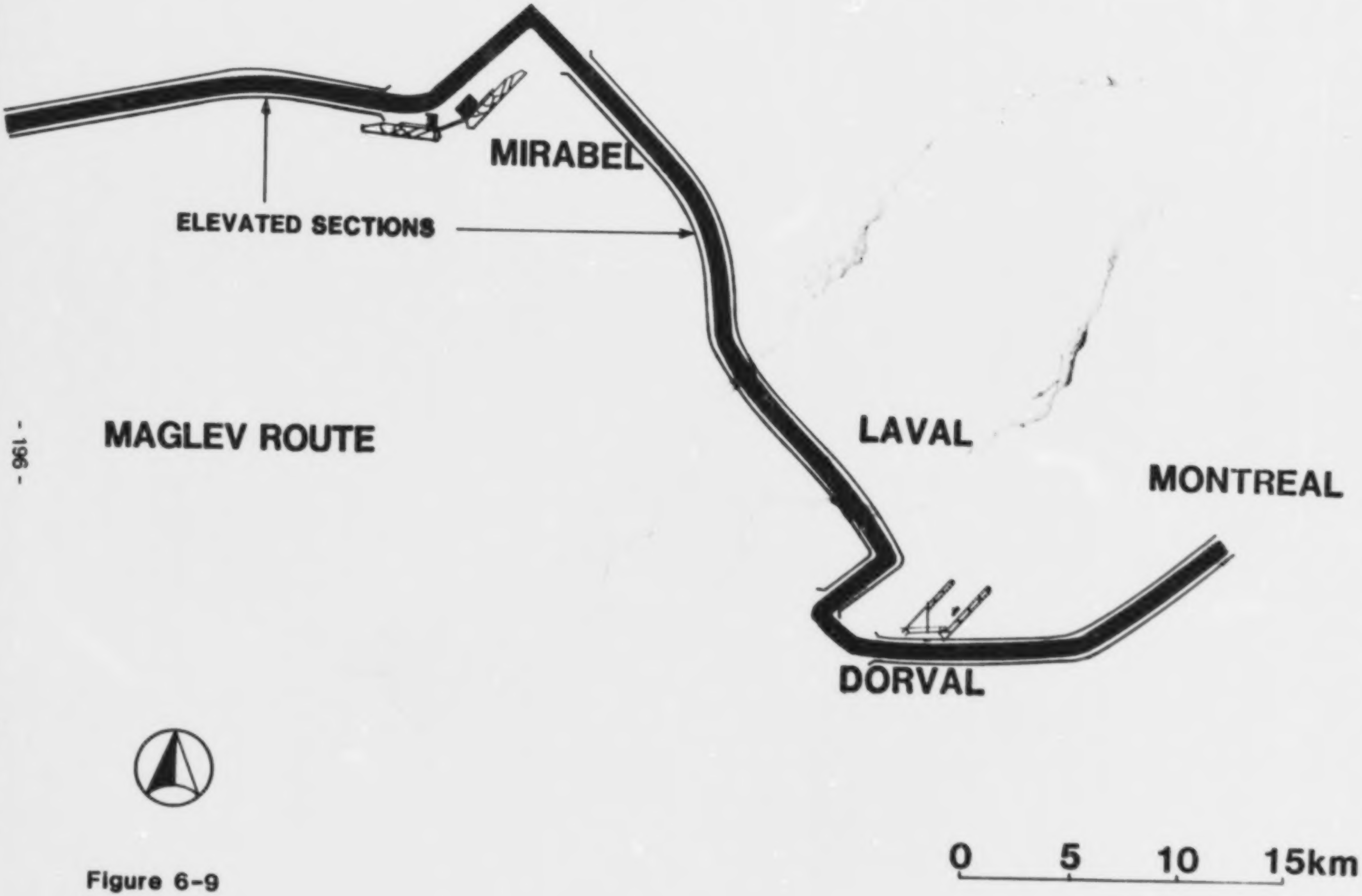

MIRABEL
ELEVATED SECTIONS
MAGLEV ROUTE
LAVAL
MONTREAL
DORVAL
0 5 10 15km

Figure 6-9

MAGLEV GUIDEWAY CONFIGURATION

rights-of-way are available there that, which now used only for infrequent passenger services.

In rural areas, a trade-off analysis must be performed to determine whether the lowest-cost solution is obtained with a guideway at grade or an elevated structure. Such an analysis has already been performed in detail by TransRapid International for German conditions. This suggested that, for rural areas with few cross roads, as in the present case, a guideway at grade was the least expensive solution.

However, a major advantage for Maglev when built in a new right-of-way is to minimize community disruption and other adverse functional impacts by being built above grade. And indeed, there are numerous farm crossings that would be cut by the construction of a guideway at grade.

Based on these considerations, the following guideway configuration was adopted: (Figure 6-7)

- elevated above tracks when built in railway rights-of-way in Montreal;
- elevated, with a 5 m clearance above the terrain:
  - . elsewhere in Montreal,
  - . in Laval
  - . in rural areas when on footings or on piles with shallow bedrock;
- at grade:
  - . in rural areas when on piles, if bedrock is deep,
  - . in and near Ottawa,
  - . in special situations, as discussed in Section F.5.

These configuration decision implies that a value of $1,14 to $1,45 M/km (for a double guideway on tangent) is placed on the benefits accruing from the use of an elevated guideway. Such benefits are chiefly related to avoiding the disruption of properties, farms and communities, that would result from the construction of a guideway at grade.

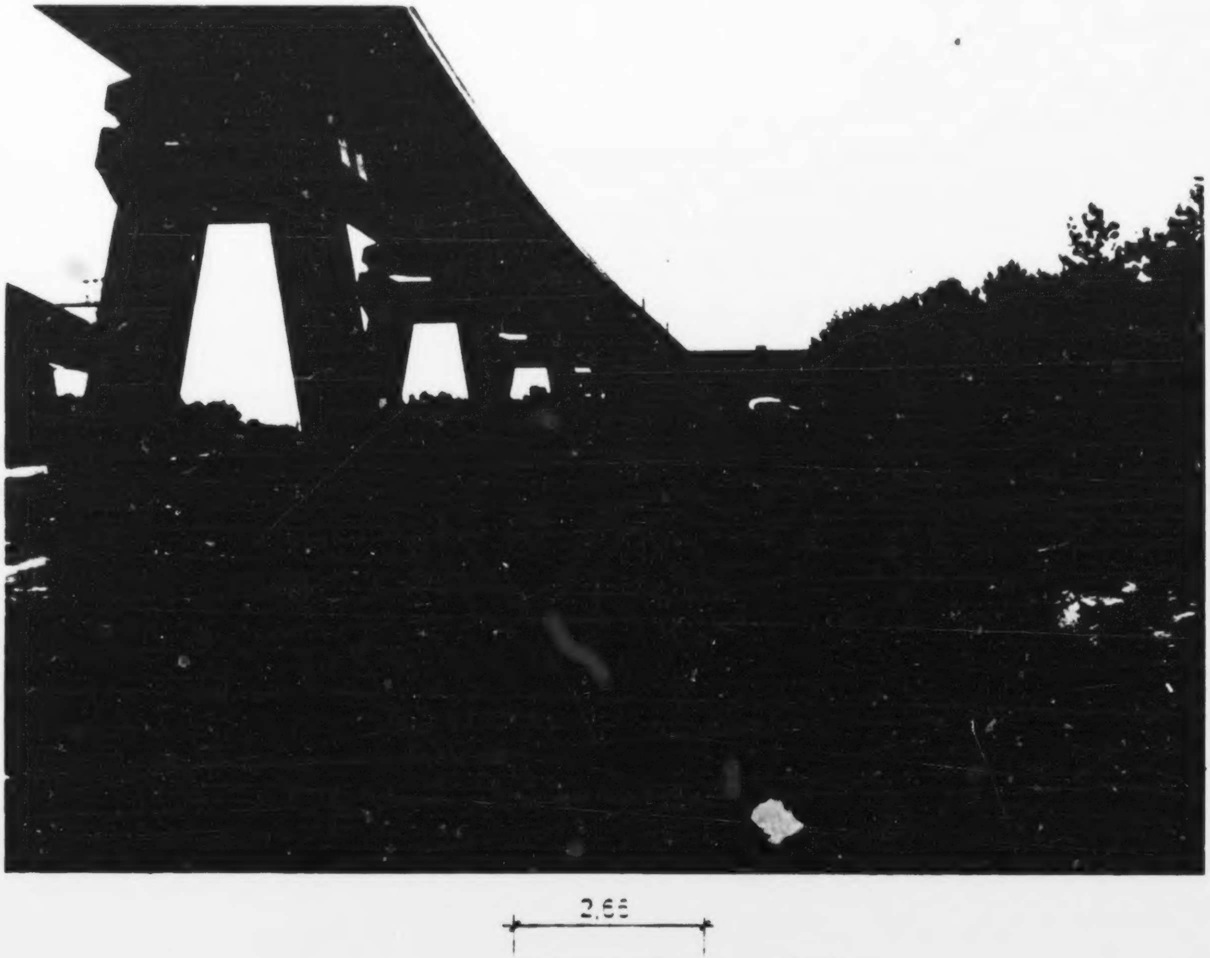

2,68
1,80
variabel

Figure 6-8 A-Shaped Pier on Piles for an Elevated Guideway

6.6.4 Beams: Design and Unit Cost

Given the design philosophy of the Maglev infrastructure, the role of the guideway beams is equivalent to that of the sub-ballast and ballast in the Rail system.

Guideway beams have been designed and can be built in three standard lengths of 25, 36, and 72 m. Under difficult conditions, longer beams of special design could be built to provide greater guideway spans.

For the Montreal - Mirabel - Ottawa application, it does not appear necessary to consider extra-long beams, as the standard lengths of 25, 36 and 72 m appear sufficient to cross the rivers and other obstacles to be encountered. Detailed investigations could indicate that, in some areas of particularly difficult sub-soil conditions, or over specific obstacles, savings might be achieved through the use of longer beams. These cases could not be considered in the present study.

Guideway beams could also be manufactured of steel. Indeed, at the Emsland Test Facility, approximately half of the test guideway is made of concrete beams and the other half of steel beams. The call for tenders for beams was subdivided into two lots and the two low bids were for different materials, with the cost differences relatively small in both cases.

To obtain the necessary quality control, the beams will be manufactured in a factory, using custom-designed and patented external and internal steel forms (Figure 6-9). Each form can be used to make one beam per day. Twenty-five meter beams can all be manufactured at one plant and transported to the site. Transport of longer beams could pose serious problems and, if there was a large number of 72 m beams, one or several beam manufacturing plants would need to be built near the site where they are needed.

The process of fabrication for the guideway beams is as follows:

- fabrication of reinforcement cage with normal and prestressing steel including inner form;
- positioning of this unit in outer form including sparing components and other devices;
- concrete pour;
- heating of the form (concrete temperature 55 - 60°C);
- primary prestressing (70% of final prestressing) when reading minimum concrete pressure of 30 N/mm^2;
- removal of the inner form;
- removal of the beam from the outer form by portal crane;
- final prestressing,
- closure of the beam at both ends.

The cost of the guideway beam has been estimated based on the construction method described above, taking into account Canadian prices for materials and labour, and presuming placement by launching with cranes installed on the guideway. Each 25 m beam would cost $25 000 in place, for a unit cost of $1,0 M per km of single guideway.

6.6.5 Bearings: Design and Unit Cost

In the Maglev system, the alignment and profile must be very finely adjusted to obtain an efficient operation of the magnetic attraction process.

This fine adjustment is obtained chiefly using precise methods and stringent tolerances when fixing the long stator and guidance rails to the guideway beam, as well as by high-quality maintenance over the years.

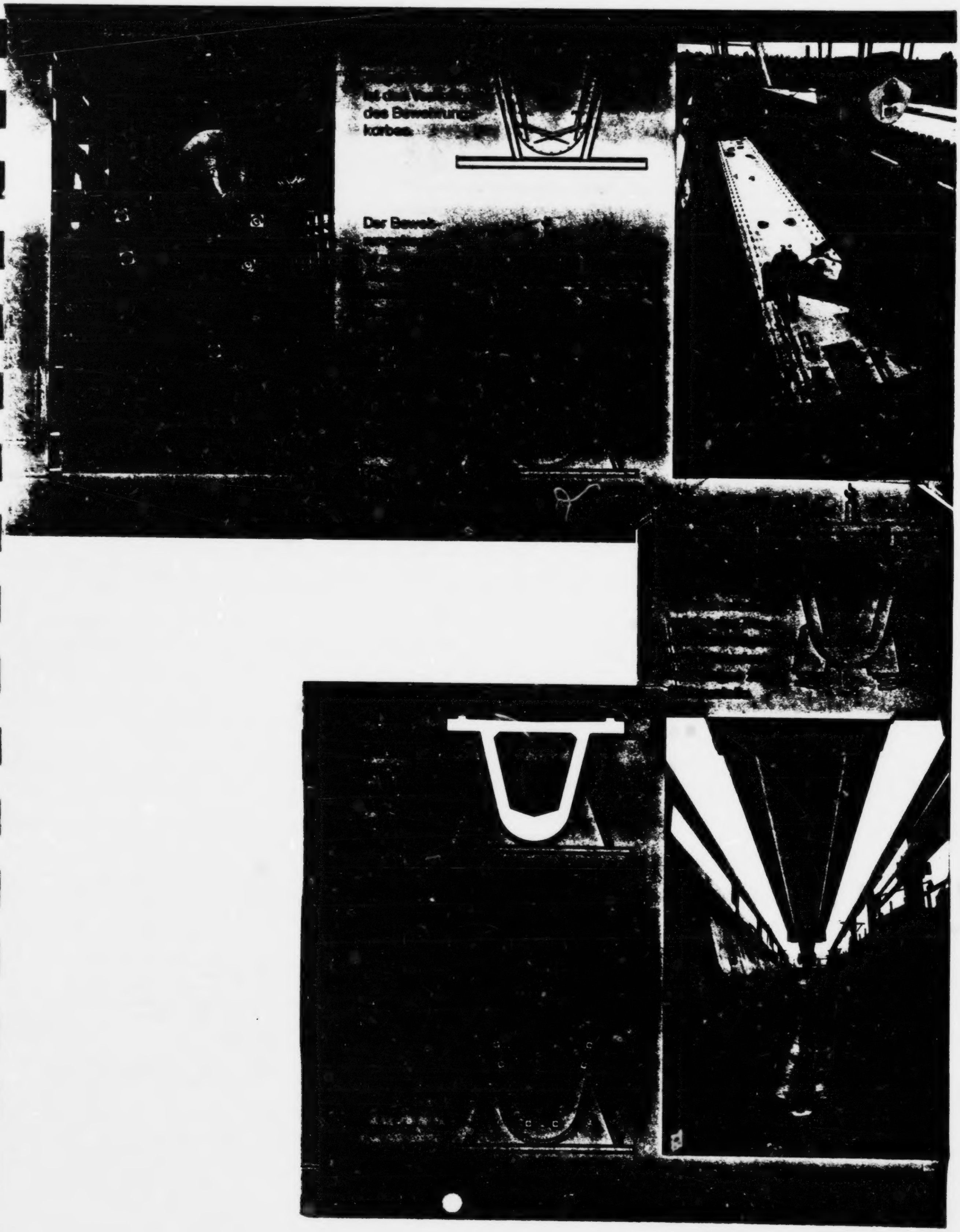

des Bewehrungs
korbes.
Der Beweh-

Figure 6-9 Fabrication Process for a guideway beam

Although allowing for some movement following significant permanent settlements of the foundations, the bearings are thus not the primary means of glide path adjustment.

Consequently, bearings of a conventional design can be used. In Emsland, the cost of bearings was equal to 4% of the costs of guideway beams and this value will be used here.

6.6.6 Piers: Design and Unit Costs

Whenever the guideway is elevated, there are two typical elements available to provide the necessary clearance between the foundation and the beam: a column with a cruciform cross-section, normally used in a tangent on good soil, and an A-shaped pier (Figure 6-8), normally used in curves or on poor soil.

A preliminary analysis has revealed that, even though it could provide important savings in materials, the cruciform column presents significant problems for pouring the concrete, as there is little room between the reinforcing bars. These pouring difficulties in turn generate quality control problems. Based on this, and considering Canadian construction practices, the use of a column does not appear warranted in this application.

The construction cost of the pier was estimated in some detail. That cost varies only with the height of the pier, as its shape is designed to provide the necessary resistance to centrifugal forces in curves. The cost of piers for various conditions is summarized in Table 6-4.

When the Maglev system is routed along a railway right-of-way, the guideway is generally built elevated over the tracks rather than at grade besides them. As a succession of A-shaped piers could present excessive interference to normal railway operations, a different structural concept was developed for that application: a rigid frame, built perpendicular to the tracks, which:

Table 6-4

Unit Costs for Guideway Piers
($CDN, 1983)

Guideway Clearance (m)	Pier Type	Pier Cost		
		Per Unit ($)	Per Guideway Km	
			Single ($M/km)	Double ($M/d.km)
0	-	-	0,0	0,0
2	A-Shape	3 400	0,136	0,272
5	A-Shape	5 500	0,22	0,44
7	A-Shape	7 700	0,28	0,56
8,5	Frame (2 tracks)	37 500	1,50	1,50
8,5	Frame (3 tracks)	52 950	2,12	2,12

Notes:
1. The A-shape piers are designed for a single guideway with 25 m beams.
2. The frames are designed for a double guideway with 25 m beams, built over railway tracks (along or across).

- carries both guideway beams;
- has its columns outside of the railway tracks over which the guideway is built, so as to leave a wider free space below;
- is rigidly connected to its own foundation elements.

Schematic designs have been studied and costed for spanning 2 and 3 railway tracks; they are discussed in Sub-section F.4.6.

6.6.7 Foundation Elements: Design and Unit Costs

The design and cost of foundation elements varies with three factors:

- the height of the guideway, measured by the clearance between the ground and the underside of the guideway beam;
- whether the guideway is straight or curved, in which case, in addition to vertical loads (static and dynamic) and longitudinal loads (due to braking forces), lateral loads (due to the centrifugal force) must be taken into account;
- the nature of the sub-soil, which dictates whether a footing (on rock or till) or a pile foundation (on sand or clay) is required.

Designs have been studied for each relevant combination of the above three factors; this is explained in detail in Section F.4.

Footings will be made of reinforced concrete and range in size from 3 to 68 m^3; they will be built in an excavation 1,5 m deep (so that they rest on soil that does not freeze) and laid on an insulating mat (to prevent heat transfer to the ground and the resulting freezing and heave).

Pile foundations consist of a reinforced concrete pile cap and four or six piles, each having to generate 500 to 1 000 kN depending on the loads. Piles will be long enough to transfer the load to bedrock (if it is shallow enough) or to generate the necessary resistance by friction.

Table 6-5

Unit Costs for Guideway Foundation Elements
($CDN, 1983)

<table>
<tr><th rowspan="3">Guideway Clearance</th><th colspan="4">Sub-Soil Type</th></tr>
<tr><th colspan="2">Rock or Till</th><th colspan="2">Sand or Clay</th></tr>
<tr><th>Straight Guideway</th><th>Curved Guideway</th><th>Straight Guideway</th><th>Curved Guideway</th></tr>
<tr><td rowspan="2">0 m (At Grade)</td><td rowspan="2">$ 750</td><td rowspan="2">$ 750</td><td colspan="2">With 5 m Piles
$3 100</td></tr>
<tr><td colspan="2">For every m additional
$ 300
to 20 m : $7 600</td></tr>
<tr><td rowspan="3">2 m</td><td rowspan="3">$ 5 550</td><td rowspan="3">$ 6 700</td><td colspan="2">With 5 m Piles
$5 700</td></tr>
<tr><td colspan="2">For every m additional: $300</td></tr>
<tr><td>to 32 m:
$13 800 max.</td><td>to 40 m:
$16 200 max.</td></tr>
<tr><td rowspan="3">5 m</td><td rowspan="3">$ 9 500</td><td rowspan="3">$11 500</td><td colspan="2">With 5 m Piles
$6 450</td></tr>
<tr><td colspan="2">For every m additional: $450</td></tr>
<tr><td>to 32 m:
$18 600 max.</td><td>to 40 m:
$22 200 max.</td></tr>
<tr><td rowspan="3">7 m</td><td rowspan="3">$13 500</td><td rowspan="3">$16 200</td><td colspan="2">With 5 m Piles
$8 250</td></tr>
<tr><td colspan="2">For every m additional: $450</td></tr>
<tr><td>to 32 m:
$20 400 max.</td><td>to 40 m:
$24 000 max.</td></tr>
</table>

Notes:
1. These foundation elements are designed for a single guideway with 25 m beams.
2. When the guideway is elevated, the use of an A-shape pier is presumed.

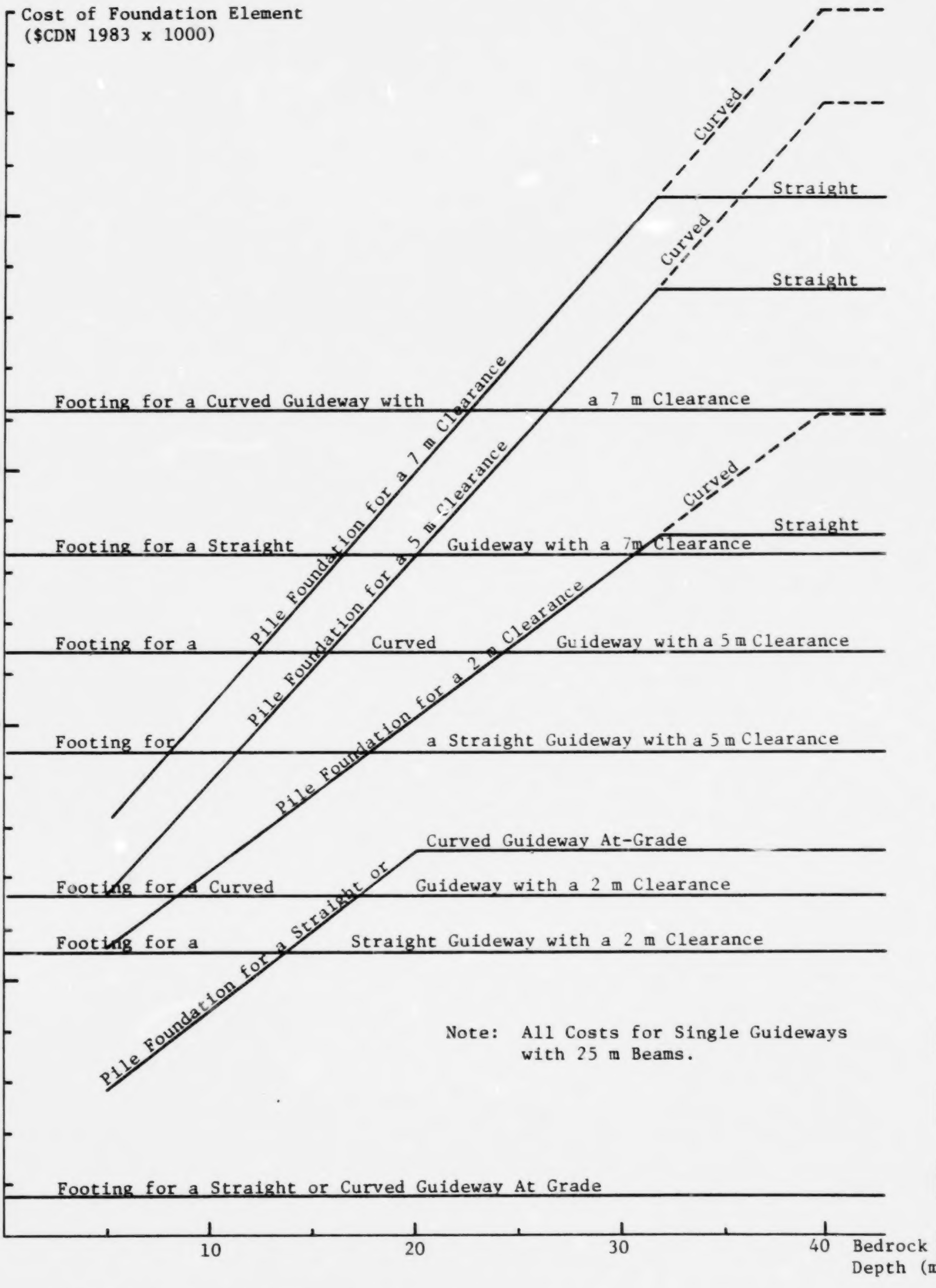


Figure 6-10 Cost Behavior of Guideway Foundation Elements

Table 6-6

Unit Kilometric Costs for Guideway Foundations and Piers
($CDN, 1983)

Guideway Clearance	Sub-Soil Type			
	Rock or Till		Sand or Clay	
	Tangent	Curve	Tangent	Curve
0 m (At Grade)	$ 0,06 M	$ 0,06 M	$ 0,25 M Minimum	$ 0,25 M Minimum
			$ 0,61 M Maximum	$ 0,61 M Maximum
2 m	$ 0,72 M	$ 0,81 M	$ 0,73 M Minimum	$ 0,73 M Minimum
			$ 1,38 M Maximum	$ 1,57 M Maximum
5 m	$ 1,20 M	$ 1,36 M	$ 0,96 M Minimum	$ 0,96 M Minimum
			$ 1,93 M Maximum	$ 2,22 M Maximum
7 m	$ 1,64 M	$ 1,86 M	$ 1,22 M Minimum	$ 1,22 M Minimum
			$ 2,19 M Maximum	$ 2,48 M Maximum
8,5 m (above 2 tracks)	$ 1,50 M	$ 1,50 M	$ 1,62 M Minimum	$ 1,62 M Minimum
			$ 2,88 M Maximum	$ 2,88 M Maximum
8,5 m (above 3 tracks)	$ 2,12 M	$ 2,12 M	$ 2,21 M Minimum	$ 2,21 M Minimum
			$ 3,47 M Maximum	$ 3,47 M Maximum

Notes:
1. These costs are for a double guideway built entirely with 25 m beams; the cost of beams and bearings is additional.
2. These costs are calculated form Tables 6-4 and 6-5.
3. For foundations built on sand or clay the minimum cost occurs when bedrock is at 5 m below ground and the maximum cost when bedrock is so deep that piles must develop their full bearing capacity through friction alone: this implies bedrock at 20 to 40 m below ground depending on the case.

The unit cost of foundation elements is given in Table 6-5 and its variation with bedrock depth (in the case of pile foundations) is illustrated in Figure 6-10.

6.6.8 Total Costs of the Basic Structure

Presuming that the guideway could be built with 25m beams only, the kilometric cost consists of:

- the cost of beams : \$ 2,00 M/km (double),
- the cost of bearings : \$ 0,08 M/km (double);
- the cost of piers : varies with clearance;
- the cost of foundations: varies with clearance and sub-soil.

The kilometric cost for foundations and piers is given in Table 6-6. Adding the cost of beams and bearings, one obtains Table 6-7. Based on a detailed analysis of the route, an inventory was performed to determine how often the various conditions are met. The results of this inventory are presented in detail in Section F.5 and are summarized in Table 6-8.

In each cell of Table 6-8, there are two data items: (in parentheses), the length over which each foundation type is used along the Maglev route (as measured in the inventory) and the estimated construction cost of that foundation type (in CDN \$1983 M), from unit costs given in or interpolated from Table 6-7.

Multiplying both values in each cell of Table 6-8 and summing over each given clearance value, one can easily determine the basic construction cost for a double guideway from Montreal to Ottawa through Mirabel, along the 189,5 km route.

That cost is estimated at \$685,7 M, which implies an average kilometric cost of \$3,62 M/km of double guideway (with 25 m beams).

Table 6-7

Unit Kilometric Costs for Guideway Construction
($CDN, 1983)

Guideway Clearance	Sub-Soil Type			
	Rock or Till		Sand or Clay	
	Tangent	Curve	Tangent	Curve
0 m (At Grade)	$ 2,14 M	$ 2,14 M	$ 2,33 M Minimum	$ 2,33 M Minimum
			$ 2,56 M Maximum	$ 2,56 M Maximum
2 m (above terrain)	$ 2,80 M	$ 2,80 M	$ 2,81 M Minimum	$ 2,81 M Minimum
			$ 3,46 M Maximum	$ 3,46 M Maximum
5 m (above terrain)	$ 3,28 M	$ 3,44 M	$ 3,04 M Minimum	$ 3,04 M Minimum
			$ 4,01 M Maximum	$ 4,30 M Maximum
7 m (above terrain)	$ 3,72 M	$ 3,94 M	$ 3,30 M Minimum	$ 3,30 M Minimum
			$ 4,27 M Maximum	$ 4,27 M Maximum
8,5 m (above 2 tracks)	$ 3,58 M	$ 3,58 M	$ 3,70 M Minimum	$ 3,70 M Minimum
			$ 4,96 M Maximum	$ 4,96 M Maximum
8,5 m (above 3 tracks)	$ 4,20 M	$ 4,20 M	$ 4,29 M Minimum	$ 4,29 M Minimum
			$ 5,55 M Maximum	$ 5,55 M Maximum

Note: These costs are applicable to a double guideway built entirely with 25 m beams.

Table 6-8

Basic Guideway Structure Costs

Guideway Clearance	Sub-Soil Type			
	Rock or Till		Sand or Clay	
	Tangent	Curve	Tangent	Curve
0 m (At Grade) (8,9 km)	$12,85 M (6,0 km)	$ 0,85 M (0,4 km)	$ 6,43 M (2,5 km)	-
2 m (6,4 km)	$ 3,80 M (1,0 km)	$ 8,93 M (3,0 km)	$ 7,86 M (2,4 km)	-
5 m (152,3 km)	$197,52 M (59,1 km)	$16,10 M (4,5 km)	$338,67 M (87,7 km)	$ 3,22 M (1,0 km)
8,5 m (over 2 tracks) (16,2 km)	$27,62 M (7,7 km)	$ 6,44 M (1,8 km)	$19,66 M (4,9 km)	$ 7,20 M (1,8 km)
8,5 m (over 3 tracks) (5,7 km)	-	-	$28,53 M (5,7 km)	-
Sub-Total by Type (189,5 km)	$241,79 M (73,8 km)	$32,32 M (9,7 km)	$401,15 M (103,2 km)	$10,42 M (2,8 km)
TOTAL	$ 685,7 M			

This basic estimate applies to the hypothetical case where the whole length of the guideway could be built with 25m beams only.

As one would expect, such an ideal situation does not occur between Montreal and Ottawa, due to three major river crossings, amongst other circumstances.

Additional guideway construction costs resulting from such situations are discussed in the next sub-section.

6.6.9 Additional Costs for Special Structures

The construction costs given at left for the Maglev structure are based on the assumption that the guideway could effectively be built:

- with a maximum clearance of 5 m except over railways;
- with a succession of 24 m spans using only standard beams of 25 m in length.

Such assumptions could possibly hold in a quasi-ideal situation, but, unfortunately, do not in the route envisioned between Montreal and Ottawa: rivers must be crossed and the guideway is sometimes built over railways.

The special structures needed to carry the guideway over railway tracks were discussed in Sub-section 6.6.6.

As for crossing rivers, a double line of piers at 25 m intervals could cause serious problem of ice accumulation in the Spring. Greater spans must thus be used to cross Rivières des-Prairies, des Mille Iles, du Nord, as well as the Ottawa and South Nation Rivers.

Furthermore, even if these rivers are relatively shallow, a clearance of 5 m is insufficient: there are, in most cases, provincial highways on both shores of the rivers. In the case of Rivière-des-Prairies, there is even a railway track near the shore, requiring 8,5 m rather than 5 m for clearance.

Furthermore, as the rivers are also narrow, it is not practical to progressively lower the guideway so that a minimum clearance is reached in the middle of the river: the resulting roller-coaster effect would be much too pronounced.

Consequently, longer spans and higher clearances will have to be used at river crossings. The corresponding structural requirements and costs (to be added to the basic cost with 25 m beams and the assumed clearances) are shown in table 6-9.

To do this, one must know the cost of a guideway with a high clearance and long spans, relative to that of a guideway with 24 m spans and a clearance of 0 or 5 m. These cost differentials were established in a detailed analysis, conducted by TransRapid International, of the variation of the construction cost of the Maglev guideway with changes in span and clearance.

These indices were used to estimate the additional cost of building a guideway structure across a river or in a situation requiring long spans and/or high clearances. Details are found in Appendix F.

Table 6-9

Cost Surplus for River Crossings

River Crossing		Foundation Type	Assumed Clearance (m)		Maglev Crossing Length (m)	Base Cost ($M)	Cost Index	Cost Surplus ($M)
			Base	Adjusted				
des Prairies	A	Piles (5 m)	5	15	216	$ 0,64	211	$ 0,71
des Prairies	B	Footings	5	15	144	$ 0,46	211	$ 0,51
des Mille-Iles	A	Piles (5 m)	5	12	216	$ 0,64	211	$ 0,71
des Mille-Iles	B	Piles (5 m)	5	12	144	$ 0,43	211	$ 0,48
du Nord		Piles (30 m)	5	15	72	$ 0,28	211	$ 0,31
Ottawa		Footings on 2 m clay	5 5	27 12	720 72	$ 2,38 $ 0,24	229 173	$ 3,07 $ 0,27
South Nation		Piles (20 m)	5	8	72	$ 0,25	211	$ 0,17
Cobbs Lake Creek		Piles (40 m)	5	8	36	$ 0,14	163	$ 0,09
TOTAL								$ 6,31

6.6.10 Total Construction Costs

Total construction costs for the Maglev guideway structure are summarized in Table 6-10.

For each given guideway clearance, all other aspects of the configuration (given along any row in Table 6-8) have been averaged out for footings and pile foundations respectively.

Due to round-off, the values in Table 6-10 can not be derived exactly from the previous tables.

Table 6-10

Summary of Maglev Guideway Structure Costs

Guideway Element	Configuration, Dimension or Clearance	Length (km)	Average Unit Cost ($M/d.km)	Total Cost (CDN$M, 1983)
Beams	25 m	189,5	2,00	379,0
Bearings	-	189,5	0,08	15,2
Piers	2 m	6,4	0,27	1,7
	5 m	152,3	0,47	67,0
Sub-Total, Piers				68,7
Foundations	0 m	8,9	0,20	1,8
	2 m	6,2	0,91	5,8
	5 m	152,3	1,13	171,7
Sub-Total, Foundations				179,3
Frames	2 tracks	16,2	1,68	27,2
	3 tracks	5,7	2,92	16,7
Sub-Total, Frames				43,9
Railway Crossings	10 u.		0,37 ea	3,7
River Crossings	8 u.		0,79 ea	6,3
Sub-Total, Crossings				10,0
TOTAL CAPITAL COST FOR GUIDEWAY STRUCTURE (CDN $M, 1983)				696,1

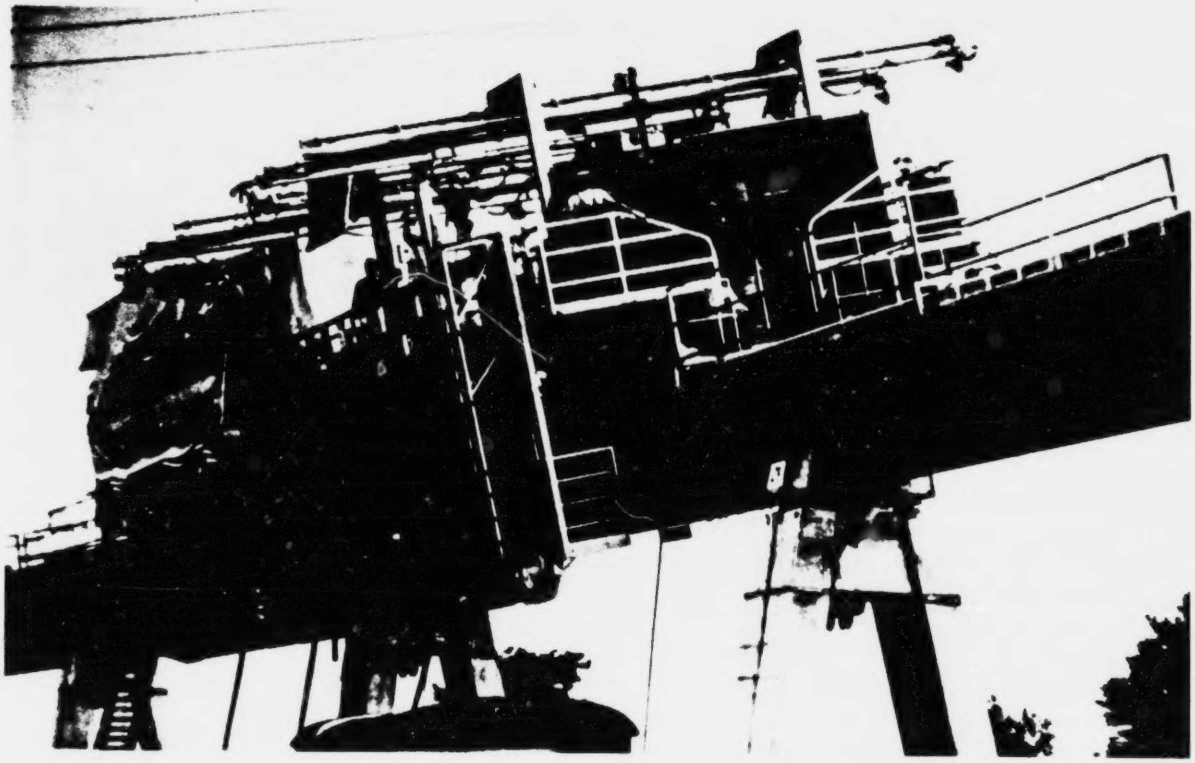


Figure 6-11 Rail Laying Train

6.7 Guideway - Mounted Equipment

Due to its functions, the guideway must carry the following equipment:

- guidance rails;
- linear motor stator consisting of:
  - . glued steel sheet lamination pack;
  - . cable windings;
- information system for command and control.

Turnouts are also a guideway equipment to be considered.

First, the process used for installing all equipment on the guideway will be described. Then the installed price will be given for each equipment. These prices have been estimated by TransRapid International and were converted directly in Canadian dollars using a conversion rate of 2,15 DM/$CDN (prevailing rate in September 1983).

6.7.1 Equipment Installation Process

Mounting the equipment on the concrete guideway is carried out by the following mobile units:

- a storage vehicle carrying the longstator packages;
- a storage vehicle carrying the guidance rails; this vehicle, together with the preceding, constitutes the rail-laying train (Figure 6-11);
- a vehicle for adjustment;
- a cable-laying vehicle (Figure 6-12);
- a milling-cutter vehicle.

The mobile units are used for laying the guidance rails, the stator components, the fixing devices for the inductive vehicle position detector, the slotted waveguide, the three-phase cable windings, and for grinding the sliding strip on the upper side of the guideway. The

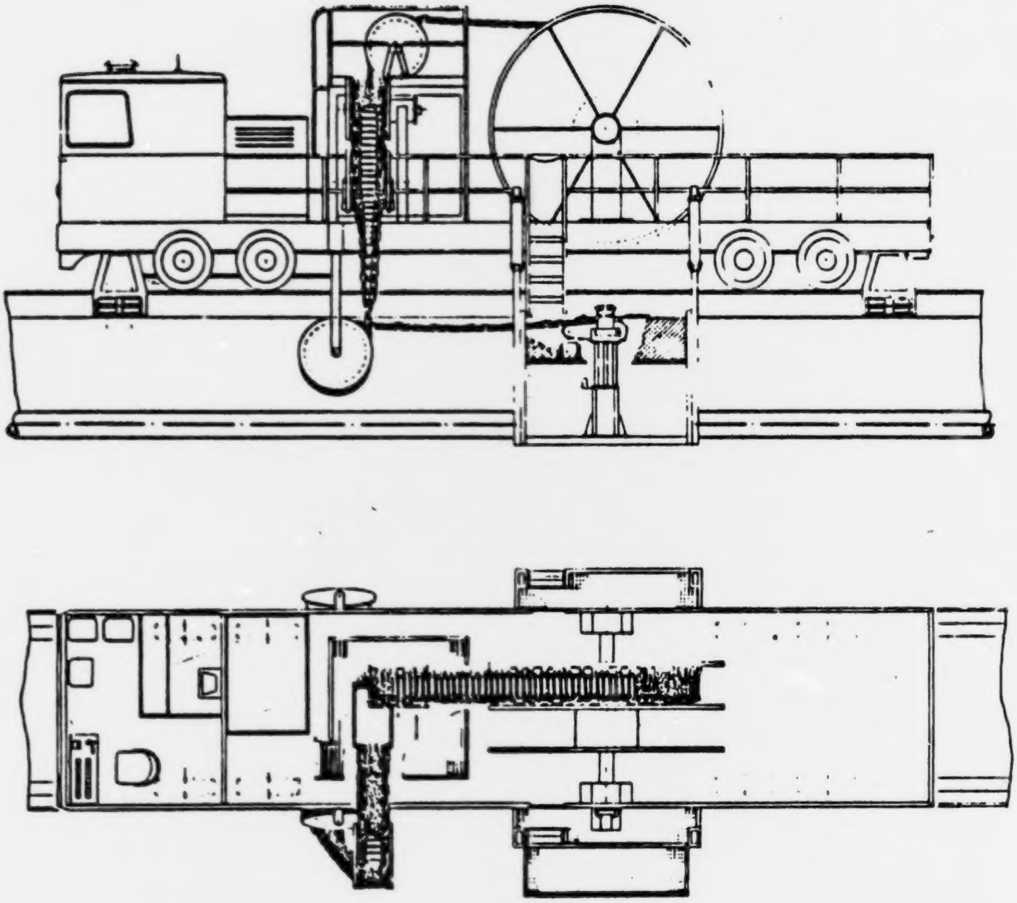


Figure 6-12 Cable-Laying Vehicle

storage vehicle is equipped with a diesel engine supplying the train with electric, hydraulic, and pneumatic energy. On-board cranes feed the rail elements into the vehicle for adjustment.

The required accuracy of the functional surfaces is ±1 mm. This tolerance is realized in such a way that a precisely fabricated adjustment frame in this vehicle will be set into the right position with servo-hydraulics. The reference line for the measurements consists of an on-board laser system. Guideway marks, positioned by geodetic survey, save as reference points for the laser beam. These marks will be detected tridimensionally by an optical sensor.

The rail-laying train works with a fixed cycle operation, each cycle requiring one hour. Twelve meters of equipment will be mounted during one cycle. A computer controls the individual steps during the operating sequence.

The rails being held in a fixed position by the adjustment frame, will then be fastened to the concrete using a special filler, which is characterized by extremely short setting times and high initial adherence.

Another vehicle is used for mounting the prefabricated windings of the stator cable. The three-phase winding is provided on a special drum and is fixed with special pressure devices between the stator packs.

The milling-cutter vehicle consists in a combination of a milling devices and grinding wheels for preparing the slide strips.

6.7.2 Guidance Rails

Guidance rails are made of a special steel (MSH), their cross section is 310 x 36 mm and their weight is 350 kg/m of double guideway.

The unit estimate for the capital cost for the electromagnetic guidance and mechanical sliding equipment includes materials and fixing devices as well as mounting of the guidance rails and forming of concrete slide strips by automated vehicles. This cost is estimated at $0,56 M per km of double guideway.

6.7.3 Long Stator

The long stator consists of a laminated steel plate and cable windings (Figure 6-13).

A glued steel sheet pack has the followings dimensions:

- a width of 180 to 185 mm (365 sheets);
- a height of 91,5 mm;
- a length of 1 031 mm.

The laminations are made of high quality steel sheets: DIN 46,400 for 170 V and 50 A. The weight of one stator pack is about 100 kg.

Cable windings are of type SGCgCFwu, with dimensions 1 x 150/15 mm, designed for 6/10 kV. The conductor is of copper, with an area 150 mm^2. The outside diameter of the windings is 32 mm and their nominal voltage is 6/10 kV.

The unit estimate for capital cost for the long stator includes the following:

Figure 6-13 Longstator Packages Mounted Below Guideway Beam
Pole Pitck : 258 mm
Width : 185 mm

- long stator pack (materials, including fixing devices, screws, nuts, bolts, special glue);
- mounting of stator packs on the guideway by an automated procedure;
- long stator cable windings (materials, fabrication and mounting of cable windings to the stator packs, including connections).

The unit capital cost is estimated at $1,25 M per km of double guideway.

6.7.4 Turnouts

The Maglev turnout consists of a continuous steel beam that is bent elastically into the branching direction (Figure 6-14).

Basically two types of turnouts are required:

- a high speed turnout (length: 132,1 m; speed, branch direction: 200 km/h; straight direction: 400 km/h; to be used for bypasses and intersections);
- a low speed turnout (length: 67,1 m; speed, branch direction: 100 km/h; straight direction: 400 km/h; to be used for stations and workshops).

The capital cost for a turnout includes concrete columns, supports, turnout beam, installation of moving and safety devices, control and monitoring apparatus, mounting (all based on series production).

Every single high speed turnout is estimated to cost $1,91 M, thus unit costs are $3,81 M for a single crossover and $7,63 for a double crossover. For low-speed turnouts, the respective estimates are $1,25 M, $2,50 M, $5,00 M.

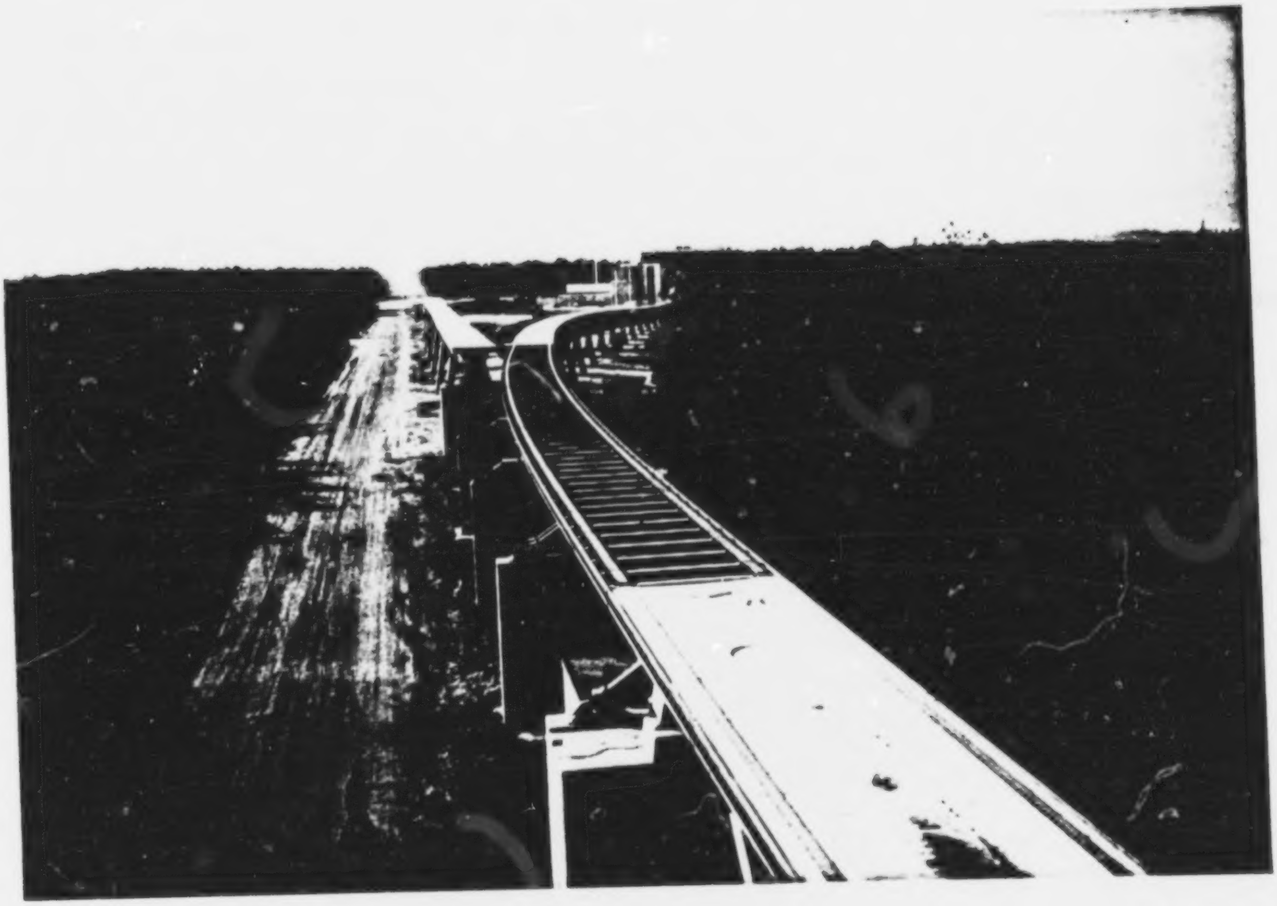


Figure 6-14 Maglev Turnout in Branching Position
Length of Turnout : 67 m
Bending Radius : 500 m
Switch Time : 20 s

6.7.5 Information System

The system consists of higher and lower operation command units, and relay equipment in sub-stations, command desks, command processors, including all communications equipment.

The cost has been estimated by Trans Rapid International at $0,58 M per km of double guideway, including the cost of the control centre. The total cost is thus, for 189,5 km, $109,5 M.

6.7.6 Guideway Equipment Costs

The estimated manufacturing and mounting costs for the guideway equipment are given in Table 6-11.

The quantities for turnouts were taken from the guideway schematic, Figure 6-5.

For the guidance rails and long stator, a provision of 2% has been added for emergency sidings and for the storage and workshop tracks, together with two additional low-speed turnouts.

Table 6-11

Capital Costs for Maglev Guideway Equipment

Item (Reference in Text)	Quantity (Unit Specified)	Unit Cost (as Specified)	Total Cost (CDN $ M, 1983)
GUIDANCE RAILS			
Rails in place	193,3 d.km	$ 0,56 M/d.km	$ 108,3 M
LONG STATOR			
Stator and Windings in place	193,3 d.km	$ 1,09 M/d.km	$ 210,7 M
TURNOUTS			
High Speed Double Crossovers	1 u.	$ 7,60 M ea.	$ 7,6 M
Low Speed Double Crossovers	3 u.	$ 5,00 M ea.	$ 15,0 M
Turnouts for Emergency Sidings	4 u.	$ 1,25 M ea.	$ 5,0 M
Turnouts for Workshop	2 u.	$ 1,25 M ea.	$ 2,5 M
Sub-Total			$ 30,1 M
INFORMATION SYSTEM	189,5 d.km	$ 0,51 M/d.km	$ 96,6 M
TOTAL CAPITAL COSTS			$ 445,7 M

Note: Cost estimates by TransRapid International in DM 1983.
Exchange rate in September 1983: 2,15 DM / CDN $.

6.8 Stations

The Maglev system will have four stations: Montreal Terminal, West Island Station, Mirabel Airport Station, and Ottawa Terminal. Their location is identified and described in Section 4.3.

The Montreal Terminal will be at Windsor Station. Three platforms will be built, their surface being approximately 9 m above concourse level. All platforms will be weather-protected and linked to the concourse level by two escalators and the central platform will, in addition, be equipped with an elevator to be used by handicapped passengers. The station will cost $3,33 M to build, including renovations. An area of 555 m^2 at concourse level will be rented from Canadian Pacific at an estimated cost of $105 000/year.

The suburban station will be located near the intersection of Boulevard Gouin, and Autoroute 13, where the Maglev guideway passes over CN Montfort Subdivision. Lateral platforms will be used on account of short headways between arriving and departing trains during peak periods; they will be elevated and weather protected. Each platform will be linked to the concourse area below with two escalators and one elevator. The station building, covering a total area of 325 m^2, will be built partly below the platforms. A parking area for 250 cars and a curb for busses, taxis, and kiss-and- ride drop-off and pick-up, will complete the station facility, which is estimated to cost $1,94 M to build.

At Mirabel Airport, the station will be located in the basement of the Terminal building, which was designed and built with a provision for such a possibility. Due to short headways between successive opposite trains and to possible passenger movements into and out of any train, two lateral platforms and one central platform will be built. Each platform will be equipped with two escalators and, in addition, there will be an elevator on the central platform for use by handicapped

Table 6-12

Capital Costs for Maglev Stations

Item (Reference in Text)	Quantity (Unit Specified)	Unit Cost (as Specified)	Total Cost (CDN $ M, 1983)
MONTREAL TERMINAL AT WINDSOR STATION			
Structural Work	-	Global	$ 1,00 M
Platforms (elevated)	2 450 m^2	$ 200 / m^2	$ 0,49 M
Escalators and Elevators	7 u.	$160 000 ea.	$ 1,12 M
Interior Finishing	-	Global	$ 0,70 M
Contingencies (5%)			$ 0,16 M
Sub-Total			$ 3,33 M
WEST ISLAND STATION			
Land Acquisition	7 000 m^2	$ 27 / m^2	$ 0,19 M
Platforms (elevated)	1 400 m^2	$ 200 / m^2	$ 0,28 M
Station Building	325 m^2	$ 550 / m^2	$ 0,18 M
Parking Lot	250 spaces	$ 11 / m^2	$ 0,09 M
Escalators and Elevators	6 u.	$160 000 ea.	$ 0,96 M
Outside and Inside Finishing	-	Global	$ 0,15 M
Contingencies (5%)			$ 0,09 M
Sub-Total			$ 1,94 M
MIRABEL AIRPORT STATION			
Structural Work	-	Global	$ 0,10 M
Platforms (modification)	2 400 m^2	$ 100 / m^2	$ 0,25 M
Escalators and Elevators	7 u.	$120 000 ea.	$ 0,84 M
Interior Finishing	-	Global	$ 0,15 M
Contingencies (5%)			$ 0,07 M
Sub-Total			$ 1,41 M
OTTAWA TERMINAL			
Structural Work	-	Global	$ 0,09 M
Platforms	2 100 m^2	$ 100 / m^2	$ 0,21 M
Tunnel and Incline	-	Global	$ 0,11 M
Finishing Work	-	Global	$ 0,10 M
Contingencies (5%)			$ 0,03 M
Sub-Total			$ 0,54 M
TOTAL CAPITAL COSTS			$ 7,22 M

travelers. On the concourse level above, an operational area of 205 m^2 will be needed for waiting, ticket transaction, and operational offices. It is presumed that this space can be made available free of charge by Transport Canada, and that Maglev travelers can use any or all airport services. The cost of building the platforms and making the necessary modifications to the building is estimated at $1,41 M.

At Ottawa Terminal, three platforms will be used also the increase operational flexibility; the two Maglev guideways will be built at grade. Passengers arriving in Ottawa will normally disembark to their right and walk from the raised platform directly into the existing station building, which will be modified as necessary to adapt to the increased traffic volume. A new tunnel will be built to link the two other platforms with the concourse; stairs between the platforms and the tunnel will be equipped with an incline wheel chair elevator. Space required for operating the service is estimated at 730 m^2 and the corresponding rental at $157 500/year. The cost of modifying the existing station and building the platforms and tunnel is estimated at $0,54 M.

Capital costs for Maglev stations are summarized in Table 6-12.

6.9 Power Supply Equipment

The energy supply for the long-stator propulsion system (for a two-section vehicle) consists of the following components:

- power supply for the substation via aerial transmission lines (underground cables could be used);
  - switchboard sections located in the transformer,
  - cable or plant aerial lines,
  - sockets, sealing ends, cables for safety control;

- substations receiving current from the utility at 115 kV, 60 Hz, and consisting of:
  - three-phase current input transformer (to obtain 20 kV, 60 Hz);
  - controllable rectifier bridge (to obtain 4-6 kV d.c.);
  - safety switch,
  - direct voltage intermediate circuit (with smoothing choke and condensor),
  - DC/AC converter sets,
  - three-phase current output transformer, switches,
  - transformer and electronics for the inverter control system,
  - cables and wires in the substation,
  - substation building;

- circuit connections:
  - switching station (building, changeover switches, cable sockets),
  - feeder with underground construction,
  - cables for power supply and for remote control.

Electric power is provided by the existing network of electric supply authorities, from overhead transmission lines. This line leads either from a transforming plant or from a branch mast of the public network to the high voltage connections of the three phase current - input transformer of the substation. The 115/120 kV switchboard plants are carried out as open air constructions.

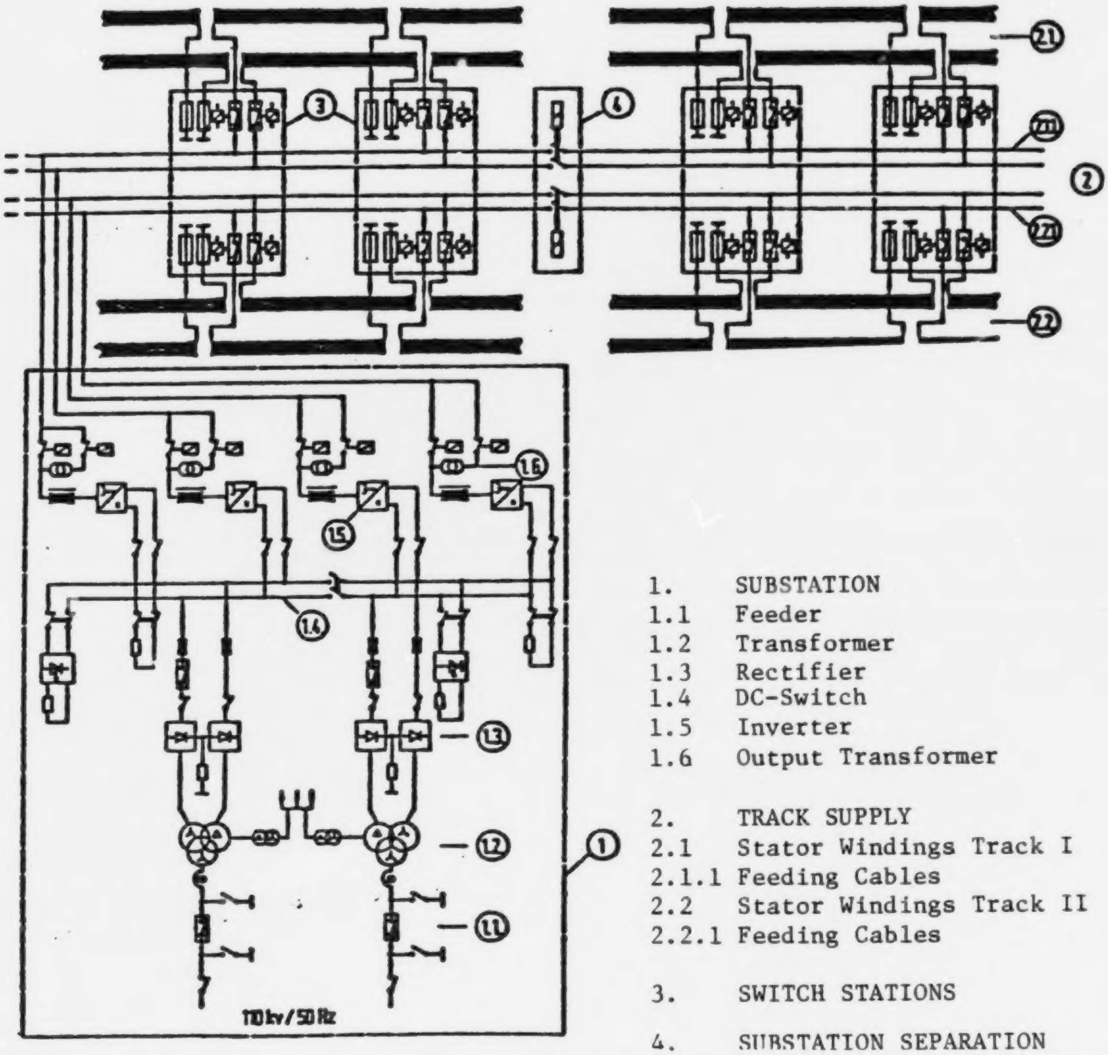
The location and number of substations are determined by the permissible feeder length and the practicability of connections to the public network. The size of the substations is defined according to the operational requirements for acceleration and speed.

Each substation contains four static inverters, two for each single guideway. A pair of static inverters is used to feed, alernatively, 400-m long sections of the guideway with current of variable frequency (0-250 Hz) and voltage (0-5 kV). Each inverter is equipped with an output transformer that raises the voltage by a factor of two for vehicle operation above 25 m/s; it will be switched on at 50 to 60 Hz.

Two different kinds of substations are provided, for acceleration and constant speed track sections. The constant speed track section is about 15 km, the acceleration track section is about 11 km, each supplied by one substation located approximately at the mid-point of the section. Each substation contains the electric capacity for supplying both sides of the double guideway (Figure 6-15).

No guideway section can be fed by two different substations. As a result, the minimum interval is limited as a function of the number of substations.

At the DC voltage level, the system in the substation is divided into two autonomous electrical parts for redundancy. The changeover switches are followed by transfo-rectifiers with branches for own requirements and for rectifier units. The DC/AC converter sets which supply the feeder cable are operated via a coupler field from the direct voltage intermediate circuit. Two three-phase cable systems


3
4
21
211
2
221
22
1.6
1.5
1.4
1.3
1.2
1.1
1
110 kV/50 Hz

1.	SUBSTATION
1.1	Feeder
1.2	Transformer
1.3	Rectifier
1.4	DC-Switch
1.5	Inverter
1.6	Output Transformer
2.	TRACK SUPPLY
2.1	Stator Windings Track I
2.1.1	Feeding Cables
2.2	Stator Windings Track II
2.2.1	Feeding Cables
3.	SWITCH STATIONS
4.	SUBSTATION SEPARATION

Figure 6-15 Longstator Power Supply Concept

are required per track which are supplied by a DC/AC converter group each. To reduce the required voltage and to increase the efficiency of traction, the three-phase cable winding in the guideway is divided into 300 to 600 m cables using switches (Figure 6-16).

For the purpose of power distribution, each part of guideway fed by a substation is subdivided into 400-m long sections that are fed consecutively.

Each guideway section is linked to substation with six cables, each of which has an equivalent copper area of 97 mm^2.

As levitation and guidance energy is fed to the vehicle by bogie-mounted linear induction generators, and propulsion power is transmitted inductively from a traveling field wave, there is no power collection through mechanical contact.

The unit costs of construction are:

- substation for acceleration section (40 MVA installed DC/AC converter performance): $9,8 M each;
- substation for constant speed section (30 MVA installed DC/AC converter performance): $7,9 M each;
- circuit connections: $0,77 M per double km of guideway.

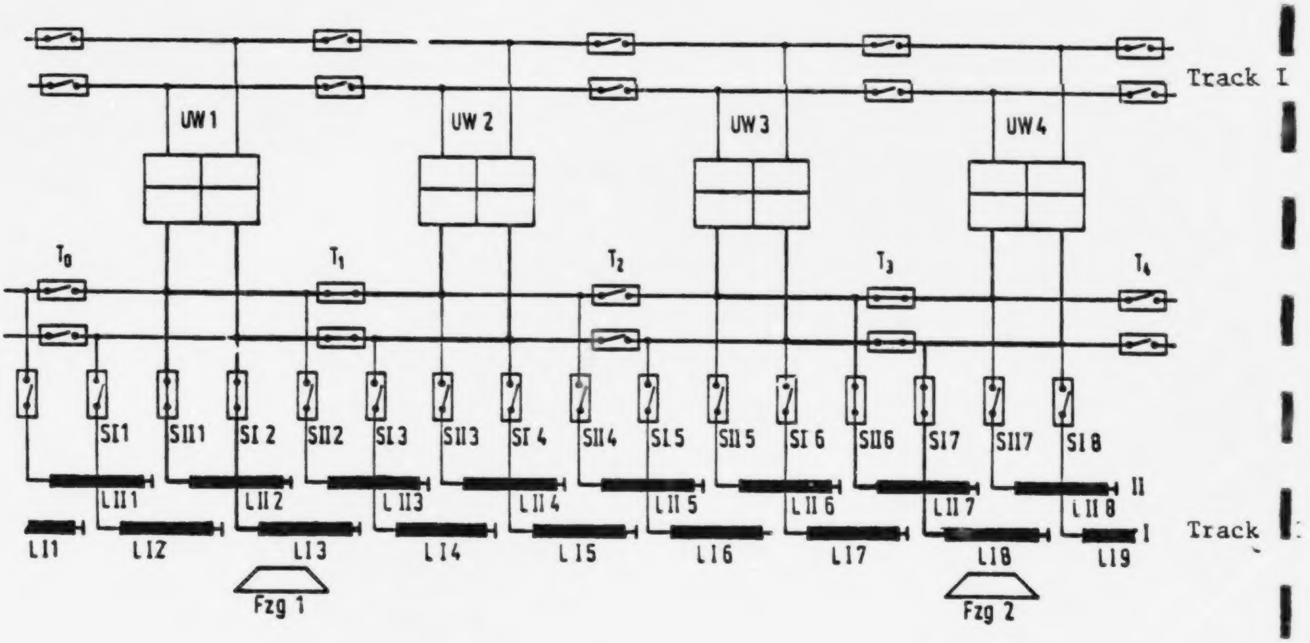
Total costs are given in Table 6-13.

Table 6-13

Capital Costs for Maglev Power Supply and Distribution

Item	Quantity (Unit Specified)	Unit Cost (as Specified)	Total Cost (CDN $ M, 1983)
SUBSTATIONS			
for acceleration section	4 u.	$ 9,8 M ea.	$ 39,2 M
for constant speed section	6 u.	$ 6,4 M ea.	$ 38,4 M
Sub-Total			$ 77,6 M
CIRCUIT CONNECTIONS	185,5 d.km	$ 0,49 M/d.km	$ 90,9 M
Sub-Total			$ 90,9 M
TOTAL CAPITAL COSTS			$ 168,5 M

* The cost of the supply network is normally included in the fixed charges made by the Utility for power consumption. In the case of Maglev, due to the importance of the supply network, some part of its construction cost could have to be borne by the system.


Track I
UW 1
UW 2
UW 3
UW 4
T_0
T_1
T_2
T_3
T_4
SI 1
SII 1
SI 2
SII 2
SI 3
SII 3
SI 4
SII 4
SI 5
SII 5
SI 6
SII 6
SI 7
SII 7
SI 8
LII 1
LII 2
LII 3
LII 4
LII 5
LII 6
LII 7
LII 8
II
I
Track
LI 1
LI 2
LI 3
LI 4
LI 5
LI 6
LI 7
LI 8
LI 9
Fzg 1
Fzg 2

Legend: UW: Substation
T: Separation Switches
S: Switches
L: Longstator
Fzg: Vehicle

Figure 6-16 Energy Supply System for Longstator Operation

6.10 Auxiliary Equipment

6.10.1 Communications

Given the sophisticated command and control system just described, communication equipment will only add a voice capability that is not essential to the system safety.

This voice capability will be used for three major functions:

- provide complementary information to the system status date relayed to central control by the signalling system;
- allow communications with freight trains and work trains that are not equipped with on-board signalling equipment;
- provide a back-up mode for permitting limited system operation in the unlikely case of a major failure of the signalling system.

To these ends, communications requirements consist of:

- a base station ($100 000)
- a radio set . at each of the four stations ($250 000 each)
  - . at the maintenance depot ($250 000)
- one on-board radio set for each of ten trainsets ($100 000 each)
- mobile radios for mobile maintenance equipment ($250 000 total).

The total cost of the communication equipment described above would amount to $3,5 M. The cost is relatively low, as this is readily available equipment sold in a highly competitive market. Also, the number of trainsets and stations is quite low compared to most transit systems, for instance.

6.10.2 Maintenance Building

The maintenance building would probably be located between Deux-Montagnes and Mirabel. In addition to providing covered space for , scheduled, and unscheduled maintenance of the fleet, the building would also house the control center and administrative offices.

All equipment related to that building (storage tracks and catenary, turnouts, control center, maintenance equipment, etc.) is described elsewhere. The assumed capital cost of $4,5 M covers only the cost of the building itself and that of the necessary office equipment.

6.10.3 Maintenance Equipment

A provision of $5,5 M has been made for fixed maintenance equipment to be located in the maintenance building. This is presumed to cover the cost of overhead cranes, wheel truing machines, and the like. Mobile maintenance equipment is discussed in Section 5.10.

6.11 Operating Procedures, Personnel, and Costs

The objective of this section is to present the evaluation of the staff required to operate the Maglev system and to estimate their salary costs, based on the operating procedures envisioned. For this purpose, personnel will be classified as follows: on-board personnel, station personnel, reservation personnel, system personnel.

For each group of personnel, three elements will be reviewed in the following order: specific procedures, staff requirements, salary costs. First, however, a brief review of system operating policies that impact on all classes of personnel.

6.11.1 Overview of System Operating Policies

The system will operate 7 days per week, 365 days per year. Every day, the first departure will be at 6h30 from each terminal and the last, around midnight. All trains will stop at both intermediate stations. All stations will be open to the public from 6h00 to 1h30. Reservation services will be offered at stations and by telephone. Telephone services will be available daily: from 9h00 to 22h00 on weekdays and from 9h00 to 21h00 on weekends and holidays.

Salaries for operating personnel would be comparable to those currently paid by VIA. Annual salary costs for various positions of interest are given in Table 6-14. These salary costs include vacation pay and other fringe benefits equivalent to 17% of the salary paid to the employee.

6.11.2 On-Board Personnel

The crew of each Maglev consist will be the following: a conductor, a pilot, and one service attendant per vehicle section, as beverage and snacks will be available on board (their direct costs are presumed to be recovered from their sale and not discussed further). There will be no on-board ticket collection or control.

All on-board personnel will report to their base station 60 min before their scheduled departure and will have a minimum layoff time of 30 min between arrival and departure. Every one will normally return to base every night. Staff will be based equally between Montreal and Ottawa.

A personnel assignment schedule has been worked out for on-board personnel, based on a cycle of 28 days. Each person would work for 4 days, then be off for three days, then work for three days, then be off for four days, then repeat the same schedule in reverse, then cycle, for a total of approximately 1184 hours of work per year, accounting for vacation.

The proposed schedule (Figure 6-2) could be covered in 1991 with one pair of five teams of 1 pilot, 1 conductor and 3 stewards working from every terminal, for a total system force of 20 pilots, 20 conductors and 60 stewards, including replacements for four-week vacations. When trains are operated with four coaches from 1993 on, 80 stewards will be required; from 1991 on, 100 stewards will be needed.

Based on Table 6-14, an annual average salary cost of $56 000 per pilot will be assumed (including fringe benefits of 17%). Total system cost for pilots would thus be $1,12 M/year on a 1983 basis.

Table 6-14

Salary Costs for Maglev Personnel

Function	Annual Salary Cost	Salary Cost per Hour
TRAIN PERSONNEL		
Pilot	$ 56 000	$ 33.65
Conductor	$ 52 000	$ 31.25
On-Board Service Agent	$ 26 000	$ 15.63
STATION PERSONNEL		
Station Manager	$ 56 000	$ 33.65
Stationmaster	$ 52 000	$ 31.25
Assistant Stationmaster	$ 40 000	$ 24.04
Ticket Agent	$ 31 000	$ 18.63
Ticket Taker	$ 31 000	$ 18.63
Baggage Handler	$ 31 000	$ 18.63
Janitor	$ 31 000	$ 18.63
COMMAND AND CONTROL PERSONNEL		
System Operation Manager	$ 52 000	$ 31.25
Terminal Supervisor	$ 43 000	$ 25.84
Dispatcher	$ 36 000	$ 21.63
Assistant Dispatcher	$ 31 000	$ 18.63
Signal Operator	$ 31 000	$ 18.63
Electrical Operator	$ 31 000	$ 18.63
OTHER PERSONNEL		
Reservation Agent	$ 31 000	$ 18.63
Clerk	$ 26 000	$ 15.63
Maintenance Agent	$ 29 000	$ 17.43

Notes: 1. Annual salary cost includes total salary paid to the employee including vacations and holidays) and the employer's cost for employee benefits such as life and sickness insurance, unemployment benefits, etc; these are equivalent to 17% of the salary paid to the employee.

2. The average productivity at VIA is 1 664 hours / year.

Based on Table 6-14 also, 1983 average annual salary costs of $52 000 for a conductor and $26 000 for an on-board service agent were assumed. Corresponding direct salary costs systemwide (in 1983 values) are estimated at $1,04 M/year for conductors and $1,56 M/year for service attendants ($2,08 M/year from 1993 to 1998, $2,50 M/year thereafter).

To this must be added, based on practice at VIA, 4% for clerical personnel and 14% for supervision, for a total annual consist operation salary cost of $4,82 M/year ($5,39 M/year from 1993, $5,85 M/year from 1999 on).

6.11.3 Station Personnel

The essential functions of a station, as this study is concerned, will be those of a ticket sales office and a waiting area. Any other functions such as personal services for passengers will be considered as self-supporting activities (including the recuperation of their appropriate capital costs) and will not be costed hereinafter. Limited baggage handling service will be available.

Passengers will show their tickets to the ticket collector before gaining access the platform upon departure, and when entering the station from the platform upon arrival: these will be the only ticket controls. Initially, there would be a 100% control which could (and probably would) eventually be replaced with a honor system with 10-15% random control.

The following positions will have to be filled at each of the four stations:

- manager:	has the executive authority for managing the station;

Table 6-15

Station Operation Personnel for Maglev

Position	Schedule	Station								Total Staff
		Montreal		West Island		Mirabel		Ottawa		
		Positions	Staff	Positions	Staff	Positions	Staff	Positions	Staff	
Station manager	9 - 5 weekdays	1	1	1	1	1	1	1	1	4
Clerical Personnel	9 - 5 weekdays	2	2	1	1	1	1	2	2	6
Station Master	At least one on duty 24 h / day 365 days / year	1	4	1	4	1	4	1	4	16
Assistant Sta. Master		1	4	1	4	1	4	1	4	16
Ticket Agents (Peak period requirements) 1991	Stations open: 20 h / day 365 days / year Variable staff through day Productivity: 1664 h/person/year	9	26	5	15	3	9	11	32	82
1996		11	31	6	18	4	11	13	38	98
2001		13	37	7	22	4	13	16	46	118
2006		14	39	8	23	4	14	17	48	124
2011		14	40	8	23	5	14	17	49	126
Ticket Taker	20 h / day	1	4	1	4	1	4	1	4	16
Baggage Handler	20 h / day	1	4	1	4	1	4	1	4	16
Janitor	20 h / day	2	8	1	4	1	4	2	8	24
Total (Peak Period) 1991	-	18	53	12	37	10	31	20	59	180
1996	-	20	58	13	40	11	33	22	65	196
2001	-	22	64	14	42	11	35	25	73	214
2006	-	23	66	15	43	11	36	26	75	220
2011	-	23	67	15	43	12	36	26	75	221

- support staff: provide administrative assistance to the station manager;
- stationmaster: direct on-line authority for the day-to-day operation of the station;
- assistant stationmaster: provides complementary supervision and assistance to station personnel where needed (such as assisting in ticket collection in peak periods);
- ticket agent: ticket sales, credits, changes, transfers, and reservations, using computerized equipment;
- ticket taker: controls tickets upon departure and cancels them upon arrival;
- baggage handler: helps passengers with their luggage upon request; there will be no checked baggage;
- janitor: for spot cleaning during the day and overall cleaning overnight.

The number of positions of each type to be filled at each station is given in Table 6-15. The staff required to fill there positions has been evaluated on the following basis:

- the manager works during business hours and is replaced by a stationmaster at other times and during his vacation;
- there is a stationmaster and/or assistant stationmaster on duty at all times;
- the station is open for service from 6h00 to 1h30 and;
- a ticket agent can perform 32 transactions per hour;
- the number of ticket agents is progressively adapted to traffic volume.

Based on salary costs given in Table 6-14 and staff requirements given in Table 6-15, the 1991 direct salary costs for station operation systemwide would be, in 1983 dollars, $6,13 M/year for all four stations.

Clerical and supervision costs do not need to be added as they are included above already. Based on experience of modern passenger railway services, a material cost of $0,80 per passenger at stations must be added, which amounts to $1,31 M/year systemwide for 1 635 000 annual passengers; it increases progressively after 1991.

6.11.4 Reservation Personnel

Reservations would be handled from a central facility located either in Montreal or at the system control center in Deux-Montagnes, using Zenith and INWATS numbers as required.

Each reservation operator would be equipped, like a station ticket agent, with a video-display-equipped intelligent on-line terminal linked to the central reservation data base. Reservation personnel requirements were computed on the basis of a productivity level equivalent to two clerk-minutes per passenger.

Based on a total annual traffic of 1 635 000 in 1991, 3,27 M clerk-minutes would be required, equivalent to 54 500 annual clerk-hours. Based on a individual productivity of 1 664 h/year, 33 clerks would be required.

Following Table 6-14, this implies, at an average annual salary cost $31 000 per agent, a system salary cost of $1,02 M for reservations, to which 4% must be added for clerical work and 14% for supervision, for a total of $1,21 M/year.

6.11.5 System Operation Personnel

System operation personnel is essentially involved in supervising consist operation, chiefly from the control centre but also, to a limited extent, from terminals.

To accomplish these functions, the following positions must be filled:

- operations manager: has the executive authority for managing all functions related to consist operation; he is assisted by support staff for administrative tasks;
- dispatcher: has the direct authority for the day-to-day operation of the system whithin established policies and procedures;
- assistant dispatcher: assists and replaces the dispatcher and performs specific functions related to the rotation of rolling stock through maintenance cycles and the administration of passenger information services;
- signal operator: is continuously involved in monitoring the signals and taking the necessary actions according to plans and procedures;
- electrical operator: is continuously involved in monitoring the power supply and distribution functions and taking the necessary actions;
- terminal supervisor: has on-line authority over all train operation staff based at his terminal; there is a terminal supervisor in Montreal and in Ottawa.

The total number of positions of each type to be filled at each station is shown in Table 6-16. The staff required has been evaluated under the following assumptions, using a productivity of 1664 hours/year.

- the manager works during business hours and is replaced by the dispatcher in charge at other times;
- there is a group of four persons on duty in the control center at all times;
- there is a terminal supervisor in duty 22 h/day.

Table 6-16

System Operation Personnel for Maglev

Position	Schedule	Base								Total Staff
		Montreal		Control Center		Mirabel		Ottawa		
		Positions	Staff	Positions	Staff	Positions	Staff	Positions	Staff	
Manager	9 - 5 weekdays	-	-	1	1	-	-	-	-	1
Clerical Personnel	9 - 5 weekdays	-	-	2	2	-	-	-	-	2
Dispatcher	24 h / day 365 days / year	-	-	1	5	-	-	-	-	5
Assistant Dispatcher	24 h / day 365 days / year	-	-	1	5	-	-	-	-	5
Signal Operator	24 h / day 365 days / year	-	-	1	5	-	-	-	-	5
Electrical Operator	24 h / day 365 days / year	-	-	1	5	-	-	-	-	5
Terminal Supervisor	24 h / day 365 days / year	1	5	-	-	-	-	1	5	10
TOTAL	-	1	5	7	23	1	5	1	5	33

Based on the personnel requirements in Table 6-16 and the unit salary costs in Table 6-14, the total 1991 salary cost for system operation would be $1,18 M, which includes clerical and supervision. Material costs are included in the signal system maintenance.

6.11.6 Maglev Operating Costs

They are summarized in Table 6-17.

Table 6-17

Breakdown of 1991 Operating Costs for Maglev
(in 1983 Dollars)

Position	Staff	Direct Salaries ($M)	Indirect Salaries ($M)	Total ($M)
Pilots	20	1,12	0,20	1,32
Conductors	20	1,04	0,18	1,22
Stewards	60	1,56	0,28	1,84
Train Operation Salaries				4,33
Material Costs for Train Operation (10%)				0,44
Total Costs for Train Operation				4,82
Station Manager	4	0,22	0,16	0,38
Station Masters	16	0,83	-	0,83
Assistant Station Masters	16	0,64	-	0,64
Station Personnel	138	4,28	-	4,28
Station Operation Salary Costs				6,13
Material Costs for Station Operation ($0.80 per passenger)				1,03
Total Costs for Station Operation				7,44
Reservation Agents	33	1,02	0,19	1,21
Salary Costs for Reservation				1,21
Material Costs: Included in Station Operation				-
Total Costs for Reservation				1,21
System Operation Manager	1	0,05	0,05	0,10
Terminal Supervisors	10	0,43	-	0,43
Dispatchers	5	0,18	-	0,18
Operators and Assistants	15	0,47	-	0,47
Total				1,18
TOTAL OPERATING COST				14,65
GENERAL AND ADMINISTRATIVE (8%)				1,17
TOTAL (CDN $M/year, 1983)				15,82

6.12 Maintenance Costs

In the case of Maglev, it is not possible to refer to existing hardware to evaluate the cost of maintenance of rolling stock and fixed equipments, since the system has not yet been operated in revenue service, not even in demonstration service.

It is nonetheless possible to obtain an appraisal of the maintenance costs that should be expected. Experience indeed shows a correlation between the useful life of structures assured as mechanical, electrical, and electronic components, and their annual maintenance costs. This correlation is expressed by maintenance factors which measure how much be spent every year for maintenance of a given equipment, as a percentage of its capital cost.

The expected useful life of each Maglev sub-system can be evaluated from its nature, its function, and its design. The corresponding maintenance factors are known from experience.

Table 6-18 shows the expected maintenance costs and how they were derived from the useful life, the maintenance factors and the capital costs, which were given earlier in the chapter.

Vehicle maintenance cost is expected to be \$5,92/M year, that is 2.22 per consist-km. Maintenance of fixed equipments is expected to be \$25,77 M/year, for a total maintenance budget of \$31,69 M/year.

Table 6-18

Maintenance Costs for Maglev

System Element	Useful Life (Years)	Maintenance Factor (%)	Capital Cost ($M)	Annual Maintenance Cost ($M/year)
VEHICLES (1991)				
Mechanical Components	30	3,0	65,8	1,97
Levitation and Guidance	15	4,7	56,9	2,67
Propulsion System	15	4,7	5,5	0,26
Command and Control Syst.	10	5,5	5,5	0,31
		(4,7)	111,5	5,21
GUIDEWAY STRUCTURE				
Beams	90	0,4	379,0	1,52
Bearings	30	3,0	15,2	0,46
Piers	90	0,4	68,7	0,27
Foundations	70	0,6	179,3	1,07
Other Structures	90	0,4	53,9	0,22
		(0,5)	696,1	3,54
GUIDEWAY EQUIPMENT				
Guidance Rails	60	0,9	108,3	0,97
Turnouts	30	2,1	30,1	0,63
		(1,2)	138,4	1,60
POWER & CONTROL				
Substations	40	1,6	77,6	1,24
Circuit Connections	32	2,0	90,9	1,82
Stator	30	2,1	210,7	4,42
Signalling System	20	2,9	96,6	2,80
Communications	20	2,9	3,5	0,10
		(2,1)	479,3	10,38
FACILITIES AND BUILDINGS				
Stations	40	1,6	7,2	0,11
Maintenance Building	40	1,6	4,5	0,07
Maintenance Equipment	40	1,6	5,5	0,09
		(1,6)	17,2	0,27
ADMINISTRATION (8%)				1,68
TOTAL (1991 in CDN $M 1983 / year)	-	-	1 442,5	22,68

6.13 Power Consumption Costs

A precise evaluation of power consumption costs would require an elaborate analysis of the expected operational patterns, to identify the importance and occurrence of peak loads on the power supply system. Such an analysis is beyond the scope of the present study, neither is it warranted, as there are significant differences between Rail and Maglev in this regard.

As a result, it appears legitimate, for estimating power consumption costs in this study, to use approximate formulas similar to those currently used by VIA Rail in its Corridor planning analyses. These formulas consider two components of power consumption costs: a demand-related component, corresponding to the fixed costs incurred by the Utility for supplying power to the system, and an energy-related component, corresponding to the market value of the energy effectively consumed for operating the Maglev system.

The following formulas provide reasonable approximations for such charges:

ACPD = 12 * MCP * ACPT * WPC * SEC * V * (S1 + S2)
ACEC = 365,25 * CKWH * ACPT * WPC * SEC * ADF * RD
where :
ACPD : Annual charge for power demand ($/year);
12 : the number of months in a year;
MCP : monthly charge for power demand ($6.66/kW/month);
ACPT : average number of sections per Maglev train (3 in 1991, Figure 6-1);
WPC : loaded weight per section (61 tonnes, Chapter 2);
SEC : specific energy consumption (0,1416 kWh/tonne-km, derived from Chapter 2);

V : maximum speed (400 km/h);

S1 : total number of sub-stations (10, Table 6-13);

S2 : number of sub-stations supplying two trains during a peak period (1, from Figure 6-2);

ACEC : Annual charge for energy consumption ($/year);

365,25: the number of days in a year;

CKWH : the unit charge for energy ($0.0157/kWh);

ADF : average daily frequency in departures per day in both directions (36, Figure 6-2);

RD : Route distance (189,5 km).

Based on the data given above, and its variation in time, power consumption costs for Maglev will be as follows:

Period	Sections/ Consist	Power consumption costs ($/year)		
		Demand	Energy	Total
1991-1992	3	$ 9,11 M	$1,01 M	$10,12 M
1993-1998	4	$12,15 M	$1,35 M	$13,50 M
1999-2011	5	$15,19 M	$1,69 M	$16,88 M

The above costs are in 1983 Canadian dollars.

7. FINANCIAL ANALYSIS AND SYSTEM OPTIMIZATION

The objective of this chapter is to present a financial analysis of the Rail and Maglev systems that were defined and costed in Chapters 5 and 6, respectively.

The first section of the chapter presents capital cost estimates for both systems and compares them: procurement and construction costs, legal, design, and engineering costs, capital costs for plant expansion and maintenance. The time-staging of these investments is also discussed.

The second section of the chapter presents and compares estimates of recurring costs for both systems: direct operating costs, maintenance costs, rental charges, power supply and consumption costs, and administrative costs. Their variation with time is discussed.

The third section introduces the concept and principles of the financial analysis to performed on both systems and outlines its objectives and expected results, while the fourth section describes the method used for performing it.

Results of the financial analysis are presented and discussed in the fifth section of this chapter, and the sensitivity of these results to variations in certain system and contextual parameters (cost escalation, demand volume, etc.) is explored.

To this point in the chapter, the comparative analysis is performed on "basic" systems i.e. the systems defined is chapters 5 and 6. Section 7.6 outlines a possible optimization of the basic Rail and Maglev systems and discusses its probable impact on the results of the financial analysis.

Table 7-1

Summary Direct Capital Costs for Rail

Item (Reference in Text)	Quantity (Unit Specified)	Unit Cost (as Specified)	Total Cost (CDN $ M, 1983)
VEHICLES FOR 1991 (Section 5.4)			
Four-car Self-propelled Trainsets	9 u.	$ 10,0 M	$ 90,0 M
Spares (5%)	-	-	$ 4,5 M
Sub-Total			$ 94,5 M
INFRASTRUCTURE (Table 5-2)			
Right-of-Way Acquisition	(239,2 ha)	Global	$ 2,6 M
Track Components	418 845 m	$ 203 / m	$ 85,2 M
Site Preparation	-	Global	$ 53,3 M
Track Base Materials	4,65 Mm^3	$ 15 / m^3	$ 83,6 M
Track Construction	418 845 m	$ 82 / m	$ 28,1 M
Turnouts	108 u.	$132 000 ea. av.	$ 14,3 M
Sub-Total			$ 267,1 M
STRUCTURES (Table 5-6)			
Grade Separations	60 u.	$552 000 ea. av.	$ 39,7 M
Special Structures	-	Global	$ 44,6 M
Bridges - short (10 m, 40 m)	10 u.	$666 000 ea. av.	$ 5,2 M
- medium (100 m)	2 u.	Global	$ 4,4 M
- Rivière-des-Prairies	1 u.	Global	$ 17,9 M
- Rivière-des-Mille-Iles	1 u.	Global	$ 17,9 M
- Ottawa Rivier	1 u.	Global	$ 26,9 M
Culverts	1 100 m	$ 165/ m av.	$ 0,2 M
Sub-Total			$ 156,8 M
STATIONS (Table 5-7)			
Montreal Terminal	-	Global	$ 0,8 M
West Island	-	Global	$ 0,7 M
Mirabel Airport	-	Global	$ 1,2 M
Ottawa Terminal	-	Global	$ 0,4 M
Sub-Total			$ 3,1 M
POWER SUPPLY AND DISTRIBUTION (Table 5-8, Sub-section 5.8.2)			
Substations	3 u.	$763 000 ea.	$ 2,8 M
Phase Breaks	-	Global	$ 0,4 M
Terminal Stations	2 u.	$ 65 000 ea.	$ 0,1 M
Catenary	194,3 km	$200 000 / km	$ 38,9 M
Sub-Total			$ 42,2 M
COMMAND AND CONTROL EQUIPMENT (Table 5-10, Sub-section 5.8.4)			
Wayside - Interlocking	-	Global	$ 27,7 M
Wayside - Other	-	Global	$ 8,9 M
Centralized Control Centre	-	Global	$ 4,5 M
Communications	-	Global	$ 3,5 M
Sub-Total			$ 44,6 M
MAINTENANCE BUILDING AND EQUIPEMENT (Sub-section 5.8.5)			$ 10,0 M
TOTAL DIRECT CAPITAL COST			$ 618,3 M

Table 7-2

Summary Direct Capital Costs for Maglev

Item (Reference in Text)	Quantity (Unit Specified)	Unit Cost (as Specified)	Total Cost (CDN $ M, 1983)
VEHICLES FOR 1991 (Section 6.4)			
End Sections	12 u.	$ 12,00 M/2	$ 72,0 M
Intermediate Sections	6 u.	$ 11,40 M/2	$ 34,2 M
Spares (5%)			$ 5,3 M
Sub-Total			$ 111,5 M
INFRASTRUCTURE (Table 6-3)			
Right-of-way Acquisition	-	Global	$ 5,2 M
Building Relocation	-	Global	$ 7,0 M
Site Preparation	-	Global	$ 19,4 M
Sub-Total			$ 31,6 M
GUIDEWAY STRUCTURE (Table 6-10)			
Beams	189,5 d.km	$ 2,00 M/d.km	$ 379,0 M
Bearings	189,5 d.km	$ 0,08 M/d.km	$ 15,2 M
Piers	158,7 d.km	$ 0,43 M/d.km av.	$ 68,7 M
Foundations: - 0 m	8,9 d.km	$ 0,20 M/d.km av.	$ 1,8 M
- 2 m	6,4 d.km	$ 0,91 M/d.km av.	$ 5,8 M
- 5 m	152,3 d.km	$ 1,13 M/d.km av.	$ 171,7 M
Special Structures:			
- Frame over 2 tracks	16,2 d.km	$ 1,68 M/d.km av.	$ 27,2 M
- Frame over 3 tracks	5,7 d.km	$ 2,93 M/d.km av.	$ 16,7 M
Railway Crossings	10 u.	$ 0,37 ea. av.	$ 3,7 M
River Crossings	8 u.	$ 0,79 ea. av.	$ 6,3 M
Sub-Total			$ 696,1 M
GUIDEWAY EQUIPMENT (Table 6-11)			
Guidance Rails	193,3 km	$ 0,56 M/km	$ 108,3 M
Long Stator	193,3 km	$ 1,09 M/km	$ 210,7 M
Turnouts: - high speed	4 u.	$ 1,90 M ea.	$ 7,6 M
- low speed	18 u.	$ 1,25 M ea.	$ 22,5 M
Information System	189,5 km	$ 0,51 M/km	$ 96,6 M
Sub-Total			$ 445,7 M
STATIONS (table 6-12)			
Montreal Terminal	-	Global	$ 3,3 M
West Island	-	Global	$ 1,9 M
Mirabel Airport	-	Global	$ 1,4 M
Ottawa Terminal	-	Global	$ 0,5 M
Sub-Total			$ 7,2 M
POWER SUPPLY (Table 6-13)			
Substations (acceleration)	4 u.	$ 9,80 M ea.	$ 39,2 M
Substations (constant speed)	6 u.	$ 6,40 M ea.	$ 38,4 M
Circuit Connections	189,5 d.km	$ 0,49 M/d.km	$ 90,9 M
Sub-Total			$ 168,5 M
AUXILIARY AND MAINTENANCE EQUIPEMENT			
Communications	-	Global	$ 3,5 M
Maintenance Building	-	Global	$ 4,5 M
Maintenance Equipment	-	Global	$ 5,5 M
Sub-Total			$ 13,5 M
TOTAL DIRECT CAPITAL COSTS			$ 1474,1 M

7.1 Analysis of Capital Costs

Chapter 5 presented a detailed description of the basic Rail system envisioned, together with an estimate of the corresponding procurement and construction costs. Similar data was presented for the Maglev system in Chapter 6. These chapters, together with their supporting appendices, contain the data that is the basis for this comparative summary and analysis of capital costs.

7.1.1 Construction and Procurement Costs

Construction costs are given for the basic Rail and Maglev systems in Tables 7-1 and 7-2, respectively. Capital costs shown in these tables cover all the sub-systems and components that are required for both HSGT systems to be fully operational on January 1, 1991.

Capital costs are given in mid-1983 canadian dollars. For estimates prepared in mid-1983 Deustchmarks by TransRapid International, a conversion rate of 2,15 DM/$CDN was adopted; this was the prevailing commercial rate in September, 1983.

7.1.2 Legal, Design, and Engineering Costs

Legal fees for the acquisition of land and relocation or demolition of buildings for the creation of a Rail or Maglev right-of-way on private land could be as high as the cost of the land or buildings itself. Consequently, a provision of 100% of the expected acquisition costs has been made for legal fees.

The cost of system design has been estimated at 1% of the total direct capital cost; accordingly, design costs would amount to $6,2 M for Rail and $14,7 M for Maglev.

The cost of professional services for preliminary and detailed engineering for sub-systems and components has been evaluated at 4% of the direct capital costs; as a result, engineering costs would amount to $24,7 M for Rail and $59,0 M for Maglev; these estimates were broken down by discipline or sub-system.

The cost of construction management services also has been evaluated at 4% of the total direct capital costs.

No estimate has been made to this point for the cost of financing the project; this will be taken into consideration in the financial analysis, as explained in Section 7.4.

7.1.3 Comparison of Capital Costs

Total capital costs are given comparatively for both systems in Table 7-3, where, sub-systems and components are not listed in the order in which they were discussed in Chapters 5 and 6; rather, they are presented in an order which facilitates the identification of the differences between both systems. Explanations follow.

In Table 7-3, "land acquisition" refers, in both cases, to the acquisition of land and the relocation of buildings necessary for creating a new right-of-way for the HSGT system; it does not include the rental of space from Railways. As Maglev is on a new right-of-way for a greater proportion of the route (85,5% versus 40,2% for Rail; Tables 5-1 and 6-2), land acquisition is naturally more important for Maglev.

For Maglev, site preparation consists only of building an access road, as the height of guideway piers can be varied with the terrain. Site preparation is more expensive for Rail, as it requires preparing a rodbed to stringent geometric and compaction standards.

For Rail, "foundations" consists of laying the foundation, sub-ballast, and ballast layers; this can be done with a high degree of mechanization. "Foundations" for Maglev consist of a large number of discrete elements, which must be built individually in place and are less amenable to production-type construction methods. This explains the cost differential.

Piers for Maglev are essentially a result of the decision to use an elevated guideway. although they are not strictly comparable, grade separations for Rail are perhaps the closes equivalent to the Maglev piers.

Guideway beams and bearings, for which there is no Rail equivalent, clearly are a requirement resulting from the use of a contact-free propulsion method: as the efficiency of the magnetic attraction varies dramatically with the air gap, beams are needed to ensure the stringent positional tolerances required for the air gap.

Special structures consist mainly of a tunnel in Mirabel for Rail; this requirement is route-related. In the case of Maglev, rigid frames to carry the guideway beams over railway tracks (approximately 14,5% of the route by length), are considered as special structures.

Track and guidance rails have essentially the same guidance function; railway tracks also have a support function filled by guideway beams in the case of Maglev. Rail turnouts are more simple than Maglev's.

Power is supplied to vehicle consists through sub-stations in both cases. In the case of Rail, the voltage drop in distribution affects the size of sub-stations. In the case of Maglev, it affects both the size and the number of sub-stations. Maglev sub-stations are also more complex because of the nature of the power supply to the guideway

Table 7-3

Comparative Capital Costs for Rail and Maglev

SECTION Item	Capital Costs (CDN $M 1983)		Cost Ratio (Maglev/Rail)
	Rail	Maglev	
VEHICLES			
Sub-Total	94,5	111,5	1,18
INFRASTRUCTURE			
Land Acquisition	2,6	12,2	4,73
Site Preparation	53,3	19,4	0,36
Foundations	83,6	179,3	2,14
Piers	-	68,7	-
Guideway Beams	-	379,0	-
Guideway Bearings	-	15,2	-
Grade Separations	39,7	-	-
Special Structures	44,6	47,6	0,94
River and Stream Crossings	72,5	6,3	0,09
Track / Guidance Rails	113,3	108,3	0,96
Turnouts	14,3	30,1	2,10
Sub-Total	423,9	866,1	2,04
POWER AND CONTROL			
Power Supply	3,3	168,5	51,06
Power Distribution	38,9	210,7	5,42
Signalling	41,1	96,6	2,35
Communications	3,5	3,5	1,00
Sub-Total	86,8	479,3	5,52
FACILITIES			
Stations	3,1	7,2	2,29
Maintenance Building	4,5	4,5	1,00
Maintenance Equipement	5,5	5,5	1,00
Sub-Total	13,1	17,2	1,31
TOTAL DIRECT CAPITAL COST	618,3	1474,1	2,38
Legal Fees	2,6	12,2	4,35
Design (1%)	6,2	14,7	2,37
Engineering (4%)	24,7	59,0	2,39
Construction Management (4%)	24,7	59,0	2,39
Sub-Total	58,2	144,9	2,49
TOTAL CAPITAL COST	676,5	1619,0	2,39

(variable in frequency and voltage) and the transformation and switching arrangements that this implies (AC to DC to AC). This is where the greatest difference in costs between the two systems occurs.

There is a very high difference also in power distribution. This is due to the relatively low power factor of the linear motor, which requires numerous circuit connections and a stator with a high level of technology. By contrast, the Rail power system is more tolerant to voltage variations and the tenary design and production are more industrialized.

Inductive signalling for Maglev explains the difference in cost for this sub-system; by contrast, the signalling technology for Rail is more mature.

Differences in cost between other components do not require much explanation.

7.1.4 Plant Expansion and Renewal Costs

The useful life of sub-systems and components is given for both systems in Table 7-4, which is derived from Tables 5-15 and 6-21; certain numbers given in the latter were modified for simplicity or comparability before inclusion in Table 7-4.

All system components have a life expectancy that is at least as long as the 20-year period chosen for the financial analysis. Consequently, no capital costs need to be incurred for plant renewal. One exception to this could be the replacement of rail in curves and grades (10% of the route) every 10 years as discussed in Sub-section 5.10.2. Since such replacement is in fact done piecewise for each curve or grade, the corresponding costs would not have to be capitalized, but could in fact be expensed. This will be assumed.

Table 7-4

Comparative Life Expectancy of System Components

SECTION / Item	Rail	Maglev
VEHICLES	20	20
INFRASTRUCTURE		
Land Acquisition	100	100
Site Preparation	100	100
Foundation	50	70
- Ballast	25	-
Structures & Bridges	50	90
- Bearings	-	20
Track / Guidance Rails	40	60
- Fence	20	-
Turnouts:	-	30
- High Speed & Diamonds	20	-
- Low Speed & Manual	40	-
POWER & CONTROL		
Power Supply	40	-
- Sub-stations	-	40
- Circuit Connections	-	30
Power Distribution (Catenary/Stator)	40	30
Signalling	40	20
Communications	20	20
FACILITIES		
Stations	50	40
Maintenance Building	40	40
Maintenance Equipment	40	40

Plant expansion will consist only of purchasing additional vehicles to handle traffic growth up to 2011. Power, control, and signalling equipment are indeed designed in the basic 1991 system to handle 2011 conditions. For Rail, nine self-propelled cars, at $2,5 M each, would be purchased for operation in 1999. For Maglev, six intermediate sections, at $5,8 M each (1983) would be purchased in 1993 for that year and again six in 1998 for operation in 1999.

Should traffic growth be greater than expected, capital costs for system expansion beyond the above would have to be considered and justified based on that unexpected growth, just like, an extension of the system to Toronto and beyond or to Quebec would have to be considered on its own merit. This will also be considered in the sensitivity analysis.

7.1.5 Time-Staging of Investments

Time-staging of investments has an influence on the total effective cost of the project, as it affects financing requirements and costs. Before starting the financial analysis, a time-staging policy had to be worked out.

This was done by analyzing the time required to produce or build the major components of the Rail and Maglev systems and deriving therefrom the time when work on these elements should start for the system to be operational in revenue service by 1 January, 1991.

From this analysis, it was concluded that design would start in the fifth year before start-up. The expenditure of capital funds by year is shown for both systems in Figure 7-1.

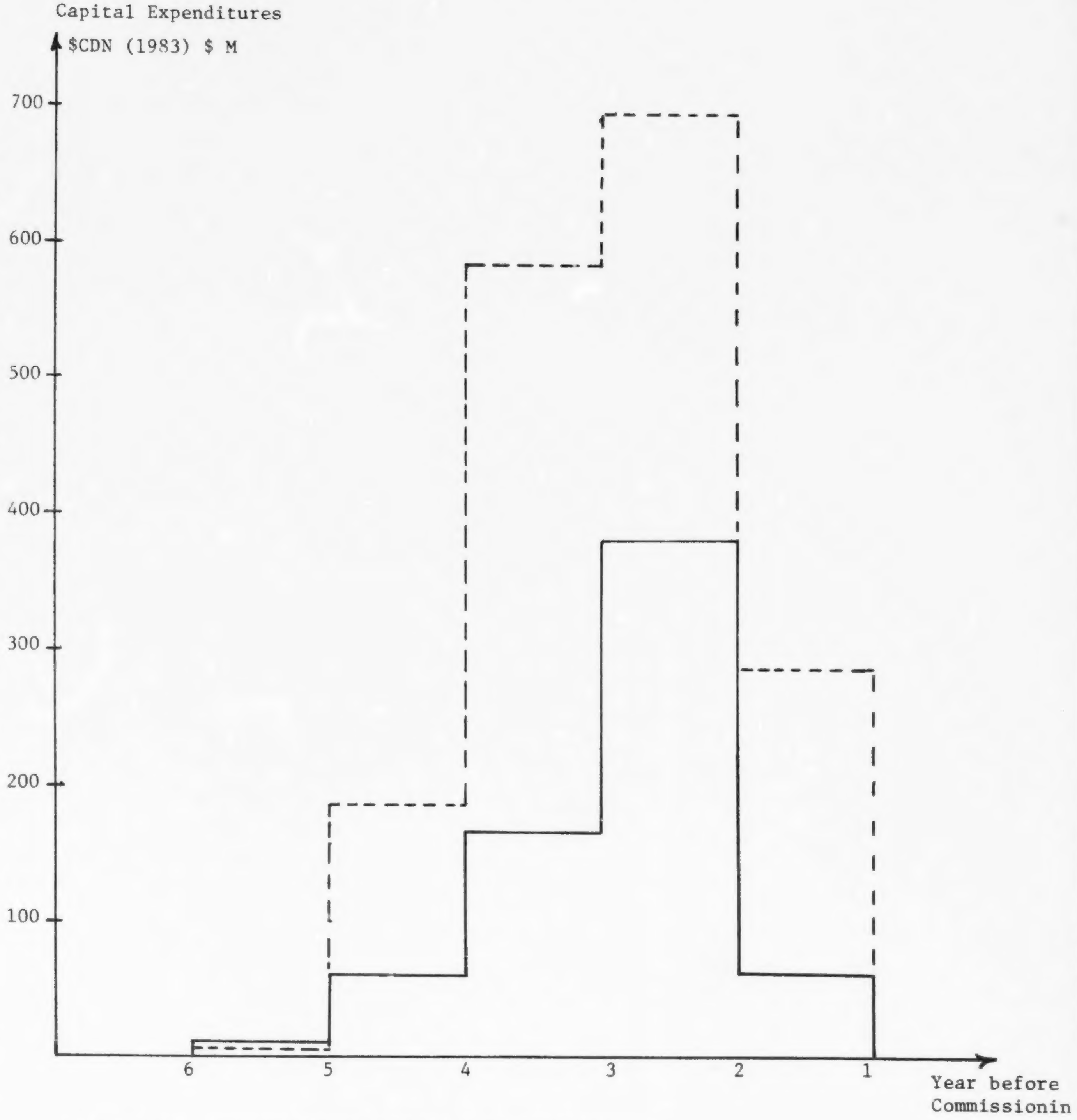


Figure 7-1 Scheduling of Capital Cost Expenditures

7.2 Recurring Costs

Recurring costs can be aggregated around the following system activities:

- operating salaries and materials;
- maintenance labour and supplies;
- power supply and energy consumption;
- land and building rentals;
- administration.

Recurring costs change in part with time as the scale of operation follows the growth of traffic: train crew and vehicle maintenance costs increase when consists are lengthened. On a longer period than 20 years, maintenance requirements could increase significantly as the plant ages.

7.2.1 Operating Salaries and Materials

These costs were discussed in Sections 5.9 for Rail and 6.11 for Maglev. Operating costs for 1991 are given comparatively in Table 7-5; the variation of their components with time (in 1983 dollars) is illustrated in Figure 7-2.

7.2.2 Maintenance Labour and Supplies

These costs were discussed in Sections 5.10 for Rail and 6.12 for Maglev. Maintenance costs for 1991 are given comparatively in Table 7-6; their components vary with time (even in 1983 dollars) as shown in Figure 7-3.

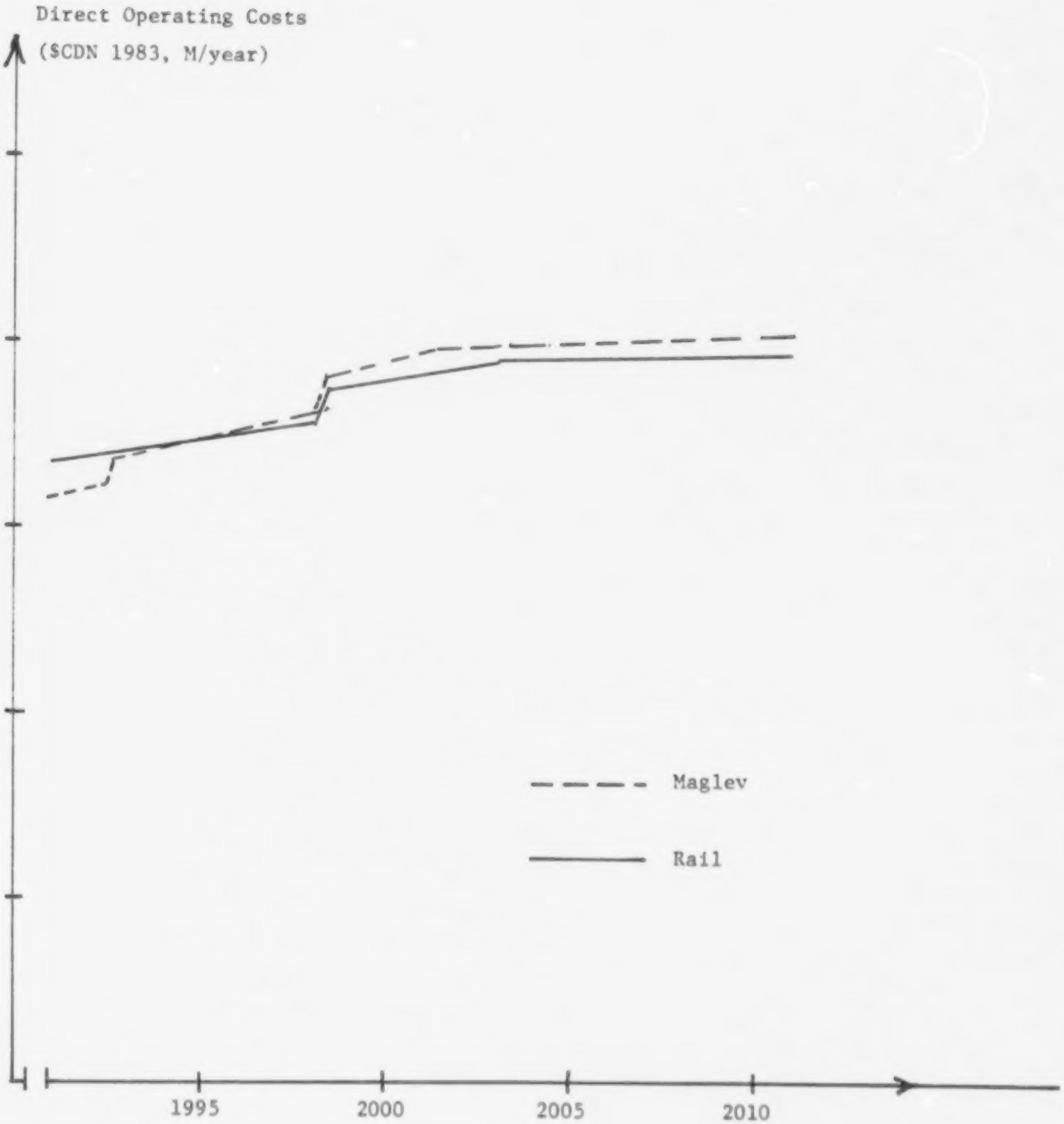


Figure 7-2 Variation of Direct Operating Costs with Time

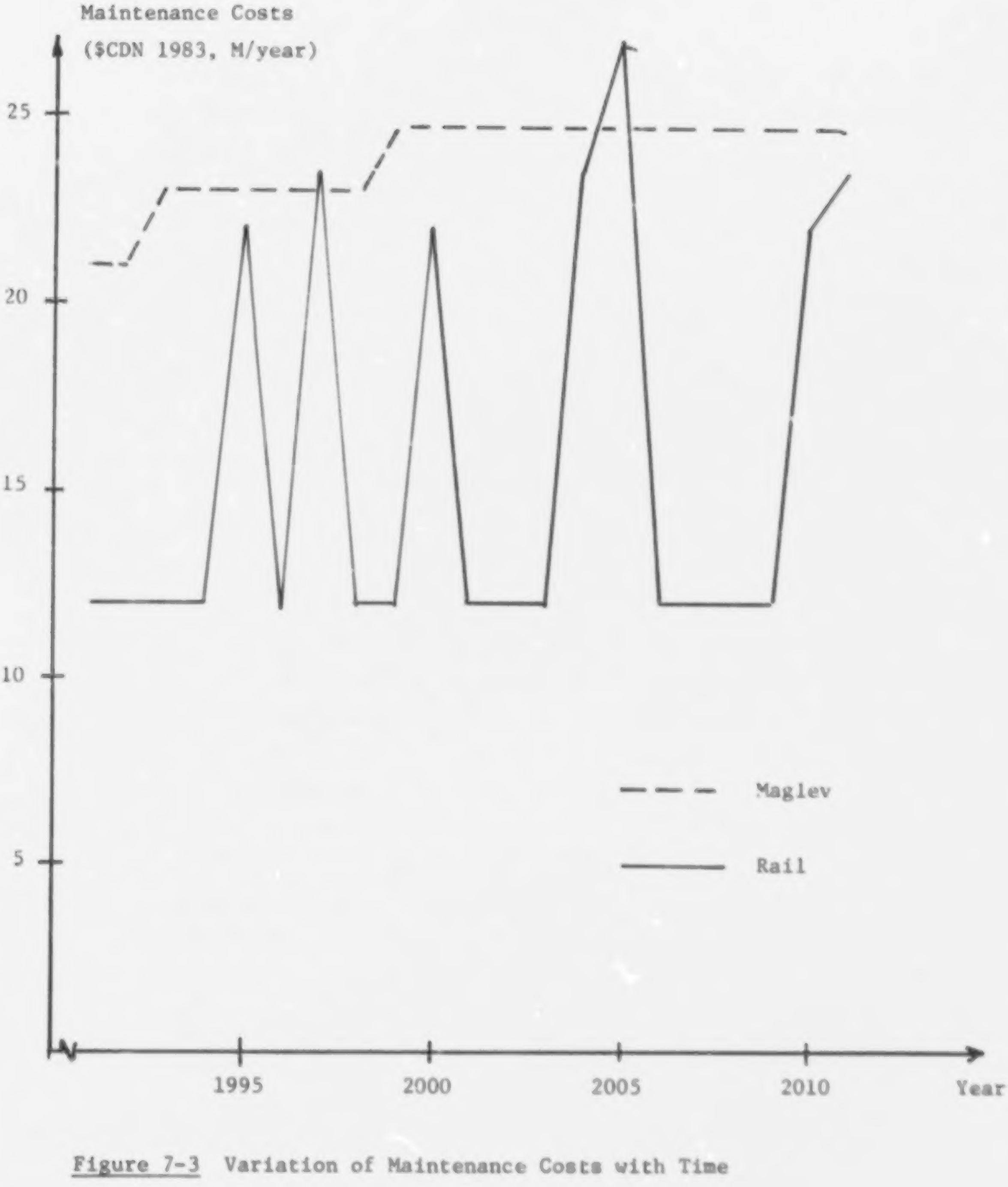


Figure 7-3 Variation of Maintenance Costs with Time

One should exert caution in comparing estimates shown in Table 7-5. Rail maintenance costs are estimated by comparison with observed costs, based on experience with existing railway systems; in those, only a moderate level of maintenance sophistication often prevails and, sometimes, preventative maintenance may have to be sacrificed in part to reduce already high operating deficits. By contrast, Maglev maintenance costs are engineering estimates derived by comparison with high-technology industries such as air transport, where a very high quality of maintenance is essential for safety, as any accident in transit is likely to be fatal. In actual HSGT operation, Maglev maintenance costs conceivably could be significantly lower than the values given in Table 7-6 and in fact probably would.

7.2.3 Power Supply and Energy Consumption

These costs were discussed in Sections 5.11 for Rail and 6.13 for Maglev.

In the case of Rail, these costs would amount initially to $1,52 M/year and would raise to $1,91 M/year in 1999. In the of case Maglev, these costs would be $10,12 M/year in 1991 and would raise to $13,49 M/year in 1993 and to $16,19 M/year in 1999 as intermediate sections are added to the Maglev consists.

The difference in costs results very largely from the fact that, whereas only three sub-stations are sufficient for Rail, Maglev requires ten on account of the relative inefficiency of the magnetic attraction process and due to the fact that power requirements increase approximately as the square of vehicle speed.

Table 7-5

Comparative Operating Costs in 1991

SECTION Item	Operating Costs ($M 1983 / year)		Rationale for difference
	Rail	Maglev	
TRAIN CREWS			
Enginement / Pilots	2,77	1,32	Shorter Maglev Turnaround
Conductors	1,53	1,22	Shorter Maglev Turnaround
Stewards	3,07	1,84	Shorter Maglev Turnaround and Consists
Material Costs (10% of above)	0,74	0,44	-
Sub-Total	8,11	4,82	
STATION PERSONNEL			
Management	0,38	0,38	Same number of Stations
Masters and Assistants	1,47	1,47	Same number of Stations
Ticket Agents	1,67	2,54	Varies with Traffic
Ticket Takers	0,50	0,50	-
Baggage Handlers	0,50	0,50	-
Janitors	0,74	0,74	-
Material Costs	1,03	1,31	Varies with Traffic
Sub-Total	6,29	7,44	
RESERVATION PERSONNEL			
Direct Cost	0,81	1,02	Varies with Traffic
Indirect Cost	0,15	0,19	Varies with Traffic
Sub-Total	0,96	1,21	
SYSTEM PERSONNEL			
Management	0,10	0,10	
Supervisors	0,65	0,43	Crew Change at Mirabel
Dispatchers	0,18	0,18	
Operators	0,46	0,47	
Sub-Total	1,39	1,18	
TOTAL	16,75	14,65	

Notes: 1. Detail on Rail Operating costs are found in Table 5-14.
2. Detail on Maglev Operating costs are found in Table 6-17.

Table 7-6

Comparative Maintenance Costs in 1991

SECTION Item	Maintenance Costs ($M 1983 / year)		Rationale for difference
	Rail	Maglev	
VEHICLES			
Sub-Total	6,22	5,21	Fewer Maglev Vehicles
INFRASTRUCTURE			
Foundations	0,15	1,07	Included in Track - Rail
Piers	-	0,27	No Piers in Rail
Beams	-	1,52	No Beams in Rail
Bearings	-	0,46	-
Structures, other	0,34	0,22	-
Track / Rails	2,18	1,60	Track includes Foundation
Sub-Total	2,67	5,14	
POWER AND CONTROL			
Power Supply	-	3,06	Many more Maglev Substat.
Power Distribution	0,78	4,42	More complex Maglev Tech.
Signalling	0,41	2,80	More advanced Maglev Tec.
Communications	0,10	0,10	-
Sub-Total	1,25	10,38	-
FACILITIES			
Stations	0,40	0,11	-
Maintenance Building	0,75	0,07	Rail includes more items
Maintenance Equipment..	0,75	0,09	Rail includes more items
Sub-Total	1,90	0,27	
TOTAL	12,04	21,00	

Notes: 1. Details on Rail Maintenance costs are found in Table 5-15.
2. Details on Maglev Maintenance costs are found in Table 6-18.

7.2.4 Land and Building Leasing

Two types of rentals must be considered: space on railway rights-of-way when the route coincides with one and space for concourse and ticket sales in Central Station, Mirabel Airport Terminal Building, and Ottawa Station.

From Sub-sections 5.5.2 for Rail and 6.5.2 for Maglev, right-of-way rental would amount to $2,8 M/year and $7,6 M/year respectively.

Based on Sections 5.7 for Rail and 6.8 for Maglev, station space rentals are $0,2 M/year and $0,26 M/year, respectively.

In total, rentals would amount to $3,0 M/year for Rail and $7,8 M/year for Maglev.

7.2.5 Administration

Administrative costs would amount to 8% of 1991 operating and maintenance costs, amounting to $2,30 M/year for Rail and $2,94 M/year for Maglev. This would not change with time.

7.2.6 Total Recurring Costs

Figure 7-4 shows the variation with time of major components of recurring costs. Total recurring costs are given in Table 7-7.

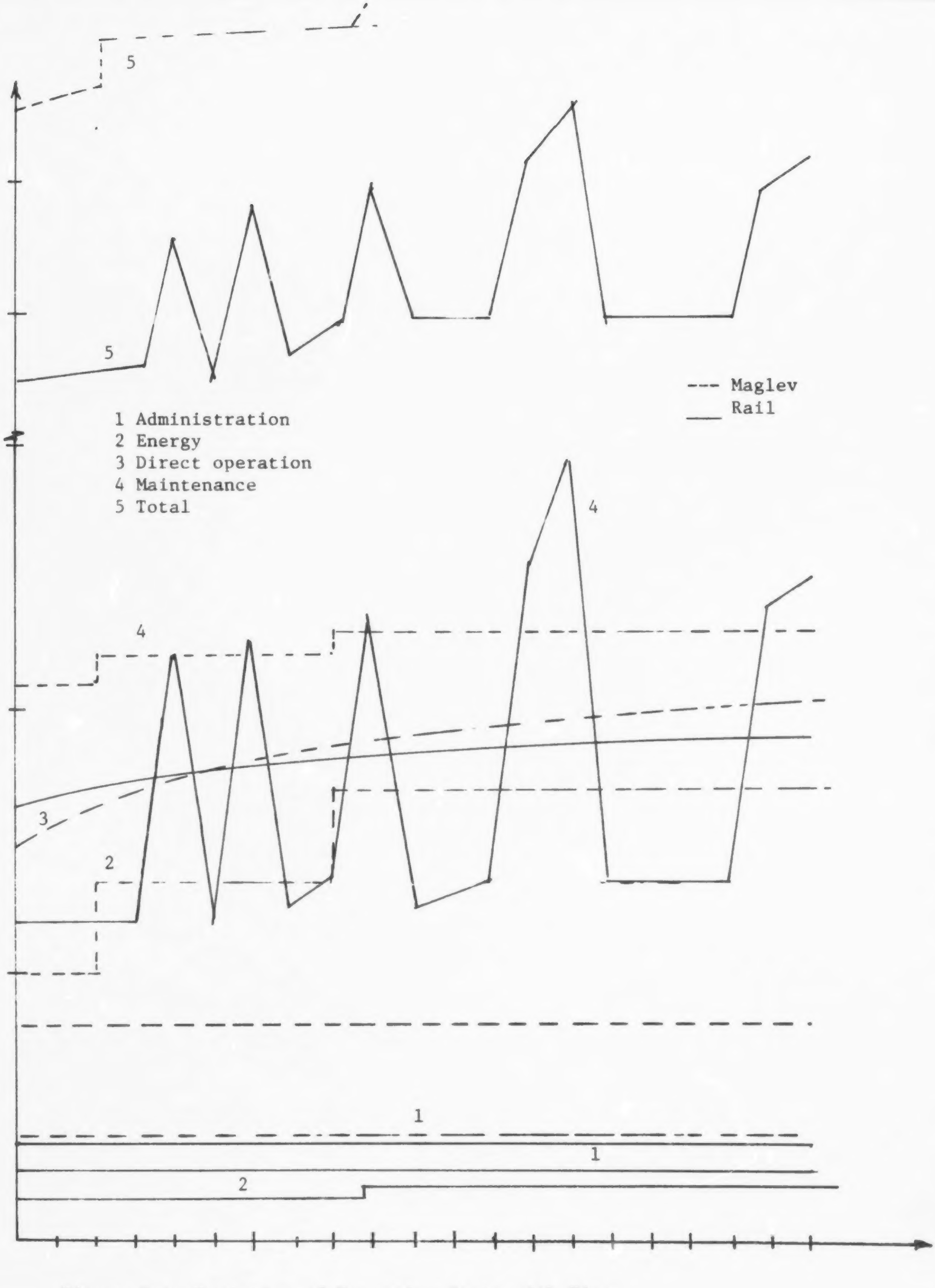


Figure 7-4 Variation of Recurring Costs with Time

)

Table 7-7

Comparative Annual Costs in 1991

SECTION Item	Maintenance Costs ($M 1983 / year)		Rationale for difference
	Rail	Maglev	
OPERATION			
Train Crews	8,11	4,82	Shorter Maglev Turnaround
Stations	6,29	7,44	Greater Maglev Traffic
Reservations	0,96	1,21	Greater Maglev Traffic
System	1,39	1,18	Shorter Maglev Turnaround
Sub-Total	16,75	14,65	
MAINTENANCE			
Vehicles	6,22	5,21	Fewer Maglev Vehicles
Infrastructure	2,67	5,14	More Elaborate for Maglev
Power and Control	1,25	10,38	More Complex for Maglev
Facilities	1,90	0,27	Rail includes more items
Sub-Total	12,04	21,00	
RENTALS			Maglev uses full Right-of-Way Width over Railways
Sub-Total	3,00	7,80	
ENERGY			Greater Maglev Speed
Sub-Total	1,52	10,12	Higher fixed monthly charges for installed power
ADMINISTRATION			
On Operation (8%)	1,34	1,17	
On Labour (8%)	0,96	1,68	
Sub-Total	2,30	2,85	
TOTAL	35,61	56,42	

7.3 Objectives of the Financial Analysis

The general objective of a financial analysis is to evaluate, using objective measures, whether an investment or project is financially warranted; specifically, the financial analysis provides the decision maker with objective criteria that can be used to answer fundamental questions such as the following:

- which solution is truly the least expensive?
- will the project yield revenues in proportion to its costs?
- is the investment justified by the expected revenues?

In the private sector, the financial analysis, by providing answers to questions such as the above, usually provides a sufficient basis for reaching a decision. Indeed, a private investment is normally justified if the project in which the capital is invested produces net revenues that are greater that interest revenues that would be obtained by simply investing the capital in financial placements. Amongst alternatives, one will opt for the project that, taking risks into account as well as time-staging of revenues, yields the highest return on investment.

In the public sector, as strict financial profitability is rarely achieved, the financial analysis is seldom a sufficient indicator as to whether the capital should or should not be invested: high-quality transportation services rarely justify their capital costs through profits alone and do not usually attract private investors. Their implementation can nonetheless be amply justified by social and economic benefits that would be quantified and evaluated in a formal economic analysis. Such an evaluation is beyond the scope of the present study. Consequently, no attempt is being made to address the issue of whether a Montreal - Ottawa Rail or Maglev system as described herein is socially or economically justified or justifiable or not.

More limited objectives are pursued by performing a financial analysis on the two systems:

- to consider capital and recurring costs jointly using a single measure of financial effectiveness;
- to consider explicitly revenues as well as costs;
- to explore the sensitivity of the financial effectiveness to variations in some exogeneous factors such as financial parameters.
- to analyze the sensitivity of the measured financial effectiveness to major changes in system design such as single-track and single-guideway systems;

The method used for pursuing these limited objectives is described briefly in the next section.

7.4 Financial Analysis Methodology

The economic analysis comparing the Maglev and the HSR technologies is based on results obtained using the MRAIL computer software, an investment analysis package developed at and maintained by the Canadian Institute of Guided Ground Transport.

Using annual estimates of capital and operating cost expenditures, the program determines an annual schedule of "revenue requirements" on a discounted cash flow basis, subject to constrains of profitability and solvency. These constraints include:

- full recovery of capital and operating expenditures;
- payment of an "appropriate" cost of funds rate annually on unrecovered investment;
- annual revenues sufficient to cover at least annual recurring costs (operations and maintenance as well as debt payments), and;
- a capital charge component which, on an annual basis, reflects the change in the replacement value of the relevant assets.

This last constraint is the one which differentiates MRAIL from other methods of investment analysis. With this method, the total capital component (in current dollars) which must be recovered from passengers system users increases each year and changes at the same rate that the replacement value of the relevant assets changes. If asset values are going up, the annual required capital component of revenue is increasing; with decreaseing asset replacement values, the annual capital component decreases.

The MRAIL approach also introduces a number of other features into the financial evaluation of the project. These include:

- automatic incorporation of inflation into the estimates of annual costs;
- use of differential cost escalation rates for different cost categories;
- use of unique annual values for inflation, cost escalation, and cost of funds rates;
- incorporation (where appropriate) of the impact of income tax including capital cost allowance, investment tax credits, and loss carry-forewards, and;
- incorporation (where appropriate) of explicit debt and equity financing packages.

7.4.1 Output Units

The primary output unit, or decision variable, used in this analysis is a year-by-year schedule of the revenue required from each Ottawa - Montreal one-way ticket. This procedure provides an efficiency measure that may be used to compare the results between the two technologies and among the various sensitivities. A simple comparison of total annual revenue requirements would not be valid due to the differences in demand and certain other characteristics.

The value of the revenue from each Ottawa - Montreal one-way ticket, simply called the "ticket cost" here, has been determined by using the Fall 1983 passenger fare structure of VIA Rail in the Central Canadian Corridor, and applying this to the actual origin-destination traffic mix projected for each year. Although there are differences in relative distance between Maglev and Rail, the same fare structure has been applied to both systems. The ticket cost for Montreal - Mirabel would be approximately 45% of the Montreal - Ottawa cost; the Mirabel-Ottawa ticket cost would be 80% of the Montreal - Ottawa level. Ticket costs for the West Island are slightly lower.

It should be noted that the ticket costs presented here are the average required values for the system operator to remain solvent and profitable. The fare schedule actually used, if one of the systems is to be implemented, may vary considerably, reflecting various discounts and premium fares. There may also be alteration in the change in fare levels from year to year. The average ticket yields, however, would have to be equal to the ticket costs presented here.

To further facilitate the analysis, a "single price" ticket cost has been developed to replace the ticket cost schedule in sensitivity analyses, where comparison of a number of annual schedules of ticket costs would be cumbersome. This "single-number ticket cost" is simply the ticket cost which would be appropriate if there were to be no changes in annual ticket costs except those generated by inflation. This single-price ticket cost yields the same discounted revenue stream as the ticket schedule, but does not necessarily satisfy the constraint of solvency in each year.

In the following sub-sections, which discuss the results of the financial analysis, all cash flows and ticket costs have been deflated to 1983 real dollar values. That is to say, all the figures have had the effects of general inflation netted out. The effects of differential cost escalation, with respect to general inflation, on individual cost components are, however, reflected in these values.

7.4.2 Financial Parameters

The financial parameters for this analysis (interest rates, inflation rates, differential cost escalation rates by cost category and labour income growth rates) were adapted from a 20-year long term trend forecast of the Canadian economy prepared in the fall of 1983 by Data Resources of Canada Inc. (DRI). These financial rates are derived out of DRI's Canadian macroeconomic model, and provide a consistent set of forecasts, with each individual component value being a function of the same set of conditions and a function of impirically observed relationships within the Canadian economy. Using such a set of internally consistent financial parameters also allows for the values of the parameters to change over time as changes are forecast in the basic economic conditions and relationships that determine interest rates and inflation rates.

The values of the financial parameters for the base case are based on an economic scenario of a strengthening of real growth over the medium term, an easing of real interest rates over the short term and a lessing of inflation. The following values have been used for the base case.

Over the period 1984 to 2000, inflation is expected to range between 6,6% and 6,0% per year, with an average value of 6,2%; this average value has been projected forward from the year 2001 on.

Real cost escalation rate differentials (in excess of general inflation) average 1% per year for labour, 0,75% per year for electricity, 0,5% for construction costs. After the year 2000, the value of these differentials has been allowed to decline to zero over a ten-year period.

Project financing has been assumed to be an equity infusion, for both systems. The cost of funds used is then the long-term government bond rate, to which has been added a real premium of 0,5% per year.

In absolute terms, these financial assumptions could be seen as somewhat unrealistic; as this financial analysis is essentially comparative, however, the choise of assumptions has little impact on the results of the comparisons.

A twenty-year period of revenue operations has been selected for the base case for both systems, as, over a longer period, significant ridership or technology changes could occur that are difficult to predict and could obscure the comparison.

No account has been taken of the residual value of assets after the twenty-year period. The sensitivity to a longer evaluation period provides an approximation of these residual values.

7.5 Financial Analysis Results

This section presents the results of the financial analysis performed on each of the two basic systems, that is the systems as described in Chapters 5 and 6, respectively. This "base case" uses the values of financial parameters just given above and is followed by various sensitivity analyses.

7.5.1 Rail System

A cash flow summary for the Rail system in the base case is presented in Table 7-8. All cash flows are given in constant (1984, $CDN) dollars and the values shown include the impact of differential cost escalation (for each cost component whenever applicable), but exclude the effect of general inflation.

The fourth column summarizes the required capital expenditures. These build up from 1986, when work starts on system design, and trail off in 1991 when revenue service begins. The capital expenditure in 1998 represents the acquisition of additional vehicles to handle passenger growth.

The fifth column presents recurring costs (operation, maintenance, energy, and administration), starting in 1991. These increase over time with traffic growth, as a result of real cost escalation (mainly labour and electrical energy), a quantum increase in 1999 results from the addition of a fifth car to all train consists.

The seventh column shows the net cash flow or equity flow. Negative values of net cash flow represent an equity infusion required, while positive values after revenue service starts in 1991 represent a return on the capital invested.

Table 7-8

Base Case Cash Flow Summary for Rail
(All Flows in millions of 1984 constant dollars)

Year	Traffic		Revenue	Capital Expend-itures	Operating Costs	Equity Flow	Montreal-Ottawa Ticket Cost ($1984)
	Millions of Riders	Millions of Pass.-km					
1984			$ 0.00	$ 0.00	$ 0.00	$ 0.00	
1985			0.00	0.00	0.00	0.00	
1986			0.00	1.92	0.00	-1.92	
1987			0.00	30.05	0.00	-30.05	
1988			0.00	161.09	0.00	-161.09	
1989			0.00	329.38	0.00	-329.38	
1990			0.00	154.34	0.00	-154.34	
1991	1.487	231.310	88.22	0.00	34.83	53.39	68.87
1992	1.542	240.293	88.84	21.36	35.31	32.17	66.80
1993	1.599	249.758	92.30	0.00	38.69	53.61	66.81
1994	1.658	259.507	92.93	0.00	39.22	53.70	64.78
1995	1.719	269.639	93.55	0.00	50.64	42.91	62.80
1996	1.782	280.153	94.13	0.00	40.20	53.93	60.85
1997	1.849	291.534	94.83	0.00	53.17	41.66	58.96
1998	1.918	303.397	95.39	0.00	41.22	54.17	57.04
1999	1.919	319.839	95.95	21.44	41.54	32.98	55.18
2000	2.065	328.398	99.93	0.00	56.53	43.40	55.28
2001	2.143	341.735	100.89	0.00	46.12	54.77	53.67
2002	2.168	346.072	101.54	0.00	46.70	54.84	53.36
2003	2.193	350.609	102.18	0.00	47.26	54.91	53.02
2004	2.219	355.089	102.80	0.00	60.78	42.02	52.68
2005	2.245	359.668	103.40	0.00	66.26	37.14	52.33
2006	2.271	364.347	103.98	0.00	48.84	55.14	51.97
2007	2.274	364.771	104.40	0.00	49.24	55.16	52.11
2008	2.276	365.254	104.78	0.00	49.60	55.18	52.25
2009	2.279	365.578	105.15	0.00	49.95	55.20	52.37
2010	2.281	366.062	105.48	0.00	50.26	55.22	52.48
2011	2.284	366.486	105.55	0.00	75.52	30.03	52.45

Notes: 1. Based upon "maximum" passenger values, double track.
2. Preliminary numbers.

The last column to the right in Table 7-8 is the schedule of average ticket costs (i.e. the cost, in real terms, of a one-way Montreal - Ottawa ticket, averaged over the various prevailing fares). Ticket cost decreases steadily over time as traffic grows and the fixed component of capital and recurring costs is distributed over a larger number of revenue passengers. After 2006, the average ticket cost rises marginally since the annual rate of traffic growth diminishes and eventually becomes lower than the real increases in recurring costs.

7.5.2 Maglev System

A cash flow summary for the Maglev system in the base case is presented in Table 7-9. The information given in that table presents essentially the same pattern as the cash flow for Rail discussed above; a slight difference: there are two quantum increases in recurring costs with the addition of a fourth and fifth section to Maglev consists in 1993 and 1999, respectively.

7.5.3 Comparison Between Rail and Maglev in the Base Case

Table 7-10 compares the calculated ticket costs (average one-way fare, in 1983 dollars, net of inflation) for the Rail and Maglev systems over the project life of twenty years.

In 1991, the Rail ticket cost is $68.87; this cost declines to $52.45 by the year 2011. For Maglev, the respective numbers are $116.01 and $84.43. At any point in time, the ratio of the Maglev ticket cost to the Rail's is slightly in excess of 1,60. Even if the changes over time were netted out by using a "single price" ticket cost over the 1991-2011 evaluation period as shown in the last row of Table 7-10, the Maglev/Rail ratio would remain essentially the same.

Table 7-9

Base Case Cash Flow Summary for Maglev

(All Flows in millions of 1984 constant dollars)

Year	Traffic		Revenue	Capital Expend-itures	Operating Costs	Equity Flow	Montreal-Ottawa Ticket Cost ($1984)
	Millions of Riders	Millions of Pass.-km					
1984			$ 0.00	$ 0.00	$ 0.00	$ 0.00	
1985			0.00	0.00	0.00	0.00	
1986			0.00	6.06	0.00	-6.06	
1987			0.00	197.61	0.00	-197.61	
1988			0.00	582.79	0.00	-582.79	
1989			0.00	662.58	0.00	-662.58	
1990			0.00	279.00	0.00	-279.00	
1991	1.899	293.208	188.74	0.00	59.68	129.07	116.01
1992	1.966	304.689	189.45	35.02	60.33	94.10	112.17
1993	2.036	316.594	196.15	0.00	67.15	129.00	111.88
1994	2.109	328.923	196.79	0.00	67.91	128.88	108.12
1995	2.184	341.736	197.39	0.00	68.59	128.80	104.48
1996	2.261	355.132	197.95	0.00	69.24	128.71	100.92
1997	2.345	369.518	198.72	0.00	69.98	128.74	97.46
1998	2.433	384.570	199.15	0.00	70.64	128.51	93.92
1999	2.523	400.204	200.17	0.00	71.45	128.72	90.80
2000	2.617	416.405	200.88	34.07	72.17	94.64	87.65
2001	2.715	433.272	208.50	0.00	88.39	120.11	87.51
2002	2.747	438.701	209.38	0.00	80.75	128.63	86.81
2003	2.778	444.187	210.24	0.00	81.64	128.60	86.11
2004	2.811	449.656	211.08	0.00	82.51	128.57	85.41
2005	2.843	455.385	211.88	0.00	83.34	128.55	84.69
2006	2.876	461.054	212.66	0.00	84.13	128.53	83.98
2007	2.879	461.579	213.29	0.00	84.78	128.50	84.13
2008	2.882	462.103	213.87	0.00	85.39	128.49	84.27
2009	2.885	462.728	214.42	0.00	85.95	128.47	84.38
2010	2.880	463.720	214.89	0.00	86.43	128.46	84.47
2011	2.891	463.777	215.03	0.00	95.62	119.41	84.43

Notes: 1. Based upon "maximum" passenger values, double track.
2. Preliminary numbers (without bearing costs).

As there appears to be no significant changes in the relative financial behavior of both systems over time, an analysis across cost components was performed. For both basic systems, Table 7-11 shows the contribution of each of the annual and capital cost components to revenue requirements. The comparison is made in 1991 and in 2011.

At the beginning of the evaluation period, both systems are similarly capital-intensive: capital charges represent 57,2% of revenue requirements for Rail and 68,4% for Maglev. The distribution between subsystems is roughly the same, with the Maglev having a higher proportion of costs in structures and electrical systems (due to the high cost of the guideway structure and power supply equipment) and the Rail a higher proportion in vehicles.

Considering recurring costs, the Maglev system draws a higher proportion of its revenue requirements from energy and maintenance costs, while, on a relative basis, the recurring costs for Rail are more significantly determined by direct operating labour costs: a direct reflection of Maglev's higher speed and shorter turnaround time.

Over time, recurring costs become more important in determining revenue requirements, but at different rates. By the year 2011, the Maglev system's revenue requirements are approximately 10% more capital-intensive than the Rail system's.

By the end of the evaluation period, the proportion of Maglev's recurring costs devoted to energy and vehicle maintenance has risen, while that for administration and fixed equipment maintenance has declined. The proportion of annual costs due to crews and station personnel does not change significantly. As for Rail, costs related to crews, station personnel, and vehicle maintenance increase slightly while those related to infrastructure maintenance and administration decrease slightly in relative terms.

Table 7-10

Comparative Ticket Costs, Base Case

Year	Rail ($ 1983)	Maglev ($ 1983)	Ratio (Maglev/Rail)
1991	$ 68.87	$ 116.01	1.68
1996	$ 60.85	$ 100.92	1.76
2001	$ 53.67	$ 87.51	1.63
2006	$ 51.97	$ 83.98	1.62
2011	$ 52.45	$ 84.43	1.61
"Single Price"	$ 57.14	$ 93.69	1.64

Notes: 1. Based on double track base case at "maximum" passenger levels.
2. Fares are for a Montreal-Ottawa one-way ticket.

Table 7-11

Revenue Contribution Requirement by Cost Component

	Rail System		Maglev System	
	1991	2010	1991	2010
OPERATING COSTS:				
Crew	9.4	12.0	2.7	3.7
Stations/Reservations	10.2	13.5	5.1	7.2
Operations	2.0	1.9	0.7	0.7
Energy	1.5	2.5	5.8	10.1
Vehicle Maintenance	5.8	9.1	2.9	4.6
Track/Guideway Maintenance	5.9	5.5	2.9	2.9
Electrical Systems Maintenance	1.6	1.5	5.9	5.7
Administration and Other	6.4	6.0	5.9	5.7
Sub-total	42.8	52.0	31.9	40.6
CAPITAL COSTS:				
Land	0.2	0.2	0.5	0.4
Vehicles	8.4	7.0	6.4	5.6
"Earthwork"	12.2	10.2	11.6	10.1
"Track"	9.4	7.9	13.6	11.9
"Structures"	13.9	11.7	19.1	16.7
"Electrical Systems"	8.2	6.9	11.2	9.8
Engineering and Management	4.9	4.1	5.7	4.9
Sub-Total	57.2	48.0	68.1	59.4
TOTAL	100.0	100.0	100.0	100.0

Notes: 1. Based on double track base case at "maximum" passenger levels.
2. Contributions of components are expressed as percentage of revenue.

7.6 Sensitivity Analysis

This section presents and discusses the various analyses performed to test the sensitivity of the basic conclusion (i.e. a Maglev/Rail "single price" ticket cost ratio of 164%) to changes in significant economic parameters. The analyses were done for the base case and only one parameter at a time was changed.

7.6.1 Traffic Volume

To test the sensitivity of the average ticket cost to traffic volume requires fixing boundaries and steps of variation for the traffic volume and determining, at each traffic level, the corresponding changes in system configuration and the associated changes in capital and operating costs.

Starting with the maximum traffic volume in 1991 (and subsequent years) as a basis, traffic levels of 40, 60, 80, 120, 160, 180, 200 and 250 per cent of the basis were considered. These changes in passenger demand were applied uniformly over all origin-destination pairs, and for each year from 1991 to 2011.

The changes in traffic volume were handled by varying only the consist size, the other system components remaining the same. As the consist size was varied, the peak-period load factor for a weekday was maintained at or below 85%.

As a result, the only capital cost that varied was that of vehicle procurement. Changes in station costs (by adapting the length of platforms to that of consists) were disegarded due to their insignificant impact on total capital costs (platform costs represent around 0,09% of total capital costs for Rail and Maglev). Operating and maintenance costs related directly (ticketing and reservation personnel salaries) or indirectly (through consist size: steward salaries, energy, and vehicle maintenance costs) to traffic were changed with changes in volumes. System operation, infrastructure maintenance, and administrative costs remained constant.

The results of that sensitivity analysis are shown in Table 7-12. As is expected with any capital-intensive project, the unit ticket cost declines with increasing passenger volume: doubling the Rail passenger demand results in a 37% decrease in the average ticket cost. As the relationship between capital costs and recurring costs is comparable in both systems, the effect on Maglev is quite similar: doubling the traffic reduces the average ticket cost by 40%.

Traffic reductions would have comparable effects on both systems.

7.6.2 Inflation and Cost Escalation

The level of general inflation is often assumed to have an impact on the revenue requirements necessary to maintain profitability and solvency for the system and, as a result on the ticket cost, which is directly related to these requirements.

In nominal terms, naturally, higher levels of inflation result in higher ticket costs and vice-versa. In real terms, however, a simple variation of the inflation rate shows little impact in ticket costs; this sumingly inconsistent result can be explained as follows:

- the financial parameters used, which are reciprocally consistent, are all linked to the inflation rate; thus, simple changes in inflation are reflected in interest rates and cost escalation rates for components;
- with the approach adopted, the annual capital charges reflect annual changes in asset values; thus, simple change in inflation are immediately reflected in the capital component of the ticket cost.

Table 7-12

Sensitivity of Ticket Cost to Traffic Volume

Traffic Volume	Rail Ticket Cost	Maglev Ticket Cost	Ratio Maglev/Rail
40 per cent of base traffic	$122.58 (2.15)	$206.12 (2.20)	1.68
60 per cent of base traffic	86.38 (1.51)	143.85 (1.54)	1.67
80 per cent of base traffic	67.60 (1.18)	111.95 1.19	1.66
BASE CASE	57.14	93.69	1.64
120 per cent of base traffic	49.38 (0.86)	80.60 (0.86)	1.63
140 per cent of base traffic	44.39 (0.78)	71.44 (0.76)	1.61
160 per cent of base traffic	40.16 (0.70)	64.75 (0.69)	1.61
180 per cent of base traffic	36.96 (0.65)	59.22 (0.63)	1.60
200 per cent of base traffic	34.21 (0.60)	55.00 (0.59)	1.61
250 per cent of base traffic	29.97 (0.52)	47.58 (0.51)	1.59
Base case, minimum traffic level	68.26 (1.19)	114.77 (1.22)	1.68
Rail at Maglev traffic level, Maglev at Rail traffic level	47.26 (0.83)	113.22 (1.21)	n/a

Notes: 1. Base on double track system, maximum passenger demand.
2. Costs for a Montreal-Ottawa one-way ticket.

Changes in expected differential cost escalation rates, however, do exert an impact on revenue requirements and ticket costs. Table 7-13 illustrates the sensitivity of the single-price ticket cost for Rail and Maglev to real (as opposed to nominal) changes in the differential escalation rates for the two major operating cost elements, labour and electrical energy.

The changes in ticket costs follow the expected pattern: they increase with increased differential cost escalation rates and vice-versa. Using a single ticket price, however, tends to average and over time the impact of changes in differential cost escalation rates for given components. A year-by-year analysis would, on the other hand tend to overstate the effects of differential inflation in the early years and understate it in later years.

More important than obtaining a precise evaluation of the impacts of component inflation on Rail and Maglev separately is assessing whether these impacts are similar or different between the two systems: this corresponds more closely the objectives of the study.

The results shown in Table 7-13 underscore the importance of energy costs for Maglev and its higher labour productivity: a higher than expected cost escalation for electricity increases the Maglev/Rail ticket cost ratio, while a higher than expected labour price index reduces it.

7.6.3 Residual Value and Project Life

Each system will have some value remaining after the twenty years of operation. Approaches to the estimation of residual values vary, from net salvage (for a system which is no longer to be operated) to replication costs (for a system that will continue). Inclusion of residual values in the analysis will lower the effective ticket cost for either system.

Table 7-13

Sensitivity of Ticket Cost to Operating Cost Escalation

	Rail Ticket Cost	Maglev Ticket Cost	Ratio Maglev/Rail
BASE CASE	$57.14	$93.69	1.64
Electricity escalation rate 1.0 per cent lower	56.95 (1.00)	92.32 (0.98)	1.62
Electricity escalation rate 1.0 per cent higher	57.39 (1.00)	95.38 (1.02)	1.66
Electricity escalation rate 2.5 per cent higher	57.87 (1.01)	98.72 (1.05)	1.71
Electricity escalation rate 5 per cent higher	59.12 (1.03)	107.41 (1.14)	1.82
Operating labour escalation rate 1.0 per cent lower	53.90 (0.94)	90.59 (0.97)	1.68
Operating labour escalation rate 1.0 per cent higher	61.12 (1.07)	97.46 (1.04)	1.59
Operating labour escalation rate 2.5 per cent higher	68.88 (1.21)	104.76 (1.12)	1.52
Operating labour escalation rate 5.0 per cent higher	88.82 (1.55)	123.31 (1.31)	1.39
Operating labour and electricity escalation rates 1.0 per cent lower	53.70 (0.94)	89.22 (0.95)	1.66
Operating labour and electricity escalation rates 1.0 per cent higher	61.36 (1.07)	99.16 (1.06)	1.62
Operating labour and electricity escalation rates 2.5 per cent higher	69.60 (1.22)	109.79 (1.17)	1.58
Operating labour and electricity escalation rates 5.0 per cent higher	90.79 (1.59)	137.03 (1.46)	1.51

SCENARIO 1: Increasing operational labour and energy escalation rate differential by 100 and 120 percent respectively.

SCENARIO 2: Increasing differential by 50 and 60 percent respectively.

SCENARIO 3: Increasing differential by 50 and 60 percent respectively.

SCENARIO 4: Increasing differential by 100 and 120 percent respectively.

Note: 1. Based on double track system. maximum passenger demand.

Residual values estimated as a percentage of the original infrastructure cost would result in no sbstantive change in the Maglev/Rail ticket cost ratio. Residual values estimated as net salvage may result in a slight improvement in the comparative position of Rail, since the cost of removing the Maglev infrastructure could be somewhat high.

For an on-going transportation system, however, a good approximation of the residual valve is the change in the ticket cost that would result from extending operations for another twenty years (the expected life of rolling stock). This approach spreads the infrastructure costs (adjusted for major renewal) over a greater number of passengers. Such an approach results on a 10% decrease in the Maglev ticket cost and an 8% decrease on the Rail ticket cost. This could underestimate the relative impact of the two systems since Maglev, being a newer technology and providing service, may be better able to resist technological obsolescence, and thus could have a longer economic life.

7.6.4 Tax and Corporate Structure

The analysis has been undertaken on the assumption that the systems would not be tax-paying entities. If they were taxable, revenue requirements would increase, but not substantially. For Maglev, the ticket cost would increase by 5%, for Rail, by approximately 9%, resulting in only a small change in the Maglev/Rail ticket cost ratio. This relationship could improve if, for example, the Maglev qualified for higher capital cost allowances, on the grounds of its being a higher technology option.

7.6.5 Financing Costs and Methods

As with inflation, the general impact of financing costs is known in advance: higher costs of funds result in higher ticket costs and vice-versa.

To explore the sensitivity of the Rail and Maglev services to the cost of funds, an analysis was performed using the long-term government bond rate without and with a risk premium of 0,5% added. Another analysis was made using the long-term average AAA corporate bond rate without and with a real risk premium of 2%. These results are summarized in Table 7-14.

Overall, the difference in impact on the average ticket cost between the two technologies is small: due to comparable capital intensivenesses, both systems show the same relative change in ticket cost for a given change in financing rates.

This preliminary analysis was undertaken assuming that an equity infusion was the only method of financing. More complex methods that are used on similar projects, such as a mix of debt and equity, will result in different revenue requirements and ticket costs. If the same financing package is used for both systems, the choice of a given method will not influence the relative cost of the two tickets noticeably.

One important question that must be raised in this regard is whether the Rail and Maglev systems are sufficiently comparable to warrant identical financial treatments.

From a market point of view, the two systems are close substitutes and would probably not warrant different financing considerations. From the cost and technological points of view, both systems are quite different, however: Maglev is significantly costlier than Rail, uses technology that is substantially less proven, and there are conceivably fewer alternate uses for its expensive infrastructure. On the other hand, the Maglev being a newer technology and offering shorter journey times, would have greater market appeal and be less susceptible to technological obsolescence.

On net, it is likely that the financial community would view Maglev as a riskier proposition than Rail and effectively demand higher rates for funds for its implementation. This would result in increasing the difference between ticket costs in the base case and in altering the relative vulnerability of the two systems to changes in the cost of funds.

7.6.6 Changes in Costs

Although every effort has been made to obtain realistic cost estimates in this study, there is still a possibility that, in reality, capital or operating costs of the Rail or Maglev could be substantially different from the values analyzed up to this point.

Costs could be different even if the estimates were never questioned. For instance, operating costs are based on salary policies now prevailing at VIA, with only a 20% increase as a technology premium for some positions on the Maglev system; the costs also presume that annual salaries could be paid to enginemen and pilots. In reality, a successful HSGT service could trigger a chain reaction of significant wage and salary increases on all operating positions and render the estimate presented herein irrelevant. Another possibility is that advances in technology could permit very significant cost savings in some Maglev sub-systems (the possibility that this could happen soon on the power supply system is already mentioned) with a noticeable influence on overall capital costs.

Table 7-14

Sensitivity of "Single Number" Ticket Cost to Financing Rate

Change in Operating Cost Escalation	Rail System		Maglev System		Ratio
	Ticket Cost ($1983)	% of Base	Ticket Cost ($1983)	% of Base	
Scenario 1	54,63	97	96,52	97	1,77
Scenario 2	56,41	100	99,93	100	1,77
BASE CASE	58,26	103	103,48	104	1,78
Scenario 3	59,78	106	106,40	106	1,78
Scenario 4	68,15	121	122,38	122	1,79

SCENARIO 1: Long-term government bond rate.

SCENARIO 2: Long-term government bond rate plus a 1 percent real premium.

SCENARIO 3: Corporate bond rate.

SCENARIO 4: Corporate bond rate plus a 2 percent real premium.

Notes:
1. Based on double track system, maximum passenger demand.
2. Costs for a Montreal-Ottawa one-way ticket.

To test the impact of such events on the revenue requirements of both systems, the sensitivity to changes in capital and operating costs was tested by calculating the average ticket cost with capital and (separately) operating costs raised and lowered by 25% and 50% respectively. This was done under base case conditions in all other respects.

The result is illustrated in Figure 7-5, which shows the variation of the ticket cost (averaged out over the twenty-year period) with changes in capital and operating costs, for both systems.

7.6.7 Conclusions

Based on the analyses discussed earlier in this section, the following conclusions can be reached.

Given the estimates of capital and annual costs, and the expected passenger demand, the Montreal - Ottawa ticket cost for a Maglev system would be slightly over 160% of that for a Rail system.

This ratio does not change significantly with passenger demand, with the level of inflation (either general or for given cost categories), the residual value of assets, the project life, the tax or corporate structure, or the financing costs and methods.

Due to differences in component life cycles, however, the relative cost advantage of the Rail system could improve with a longer project life, especially considering that, in reality, financing costs might be more onerous for the Maglev system due to perceived or presumed greater risks.

Any significant change in capital or annual costs for one system only would naturally change the ratio of ticket costs. The change would be greatest for a given percentage costs in the capital costs for Maglev, as they an important component of the ticket cost.

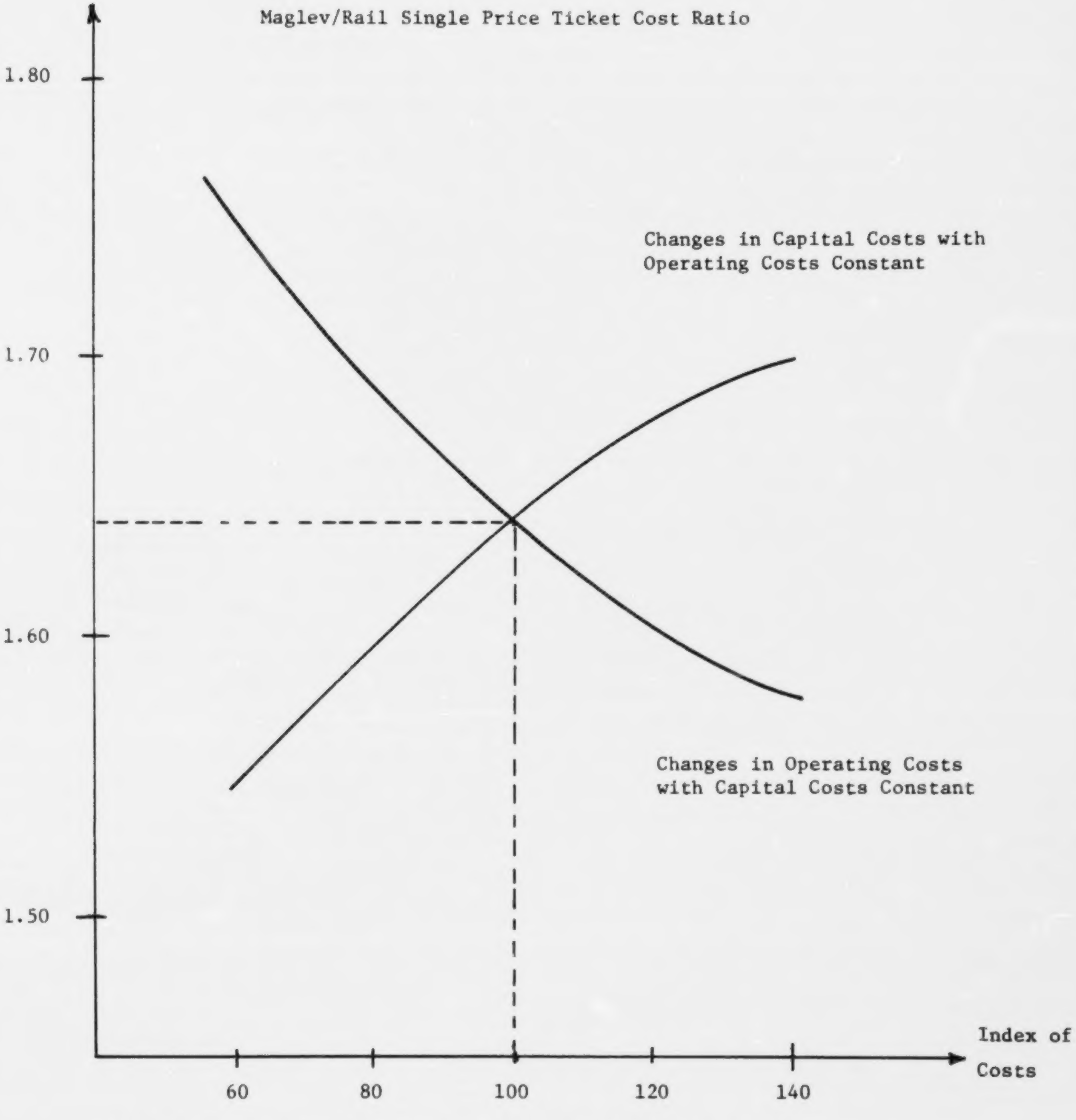


Figure 7-5 Variation of Ticket Cost with Changes in Costs

The difference in ticket costs, however, is not a parameter that can, alone, assess the desirability of any of the two systems, as the services that they offer are not comparable.

The comparison is between two technologies that have reached quite different stages in their development: Rail is a mature technology while Maglev is in the early stages of it development potential. This is not reflected in the financial analysis and a satisfactory assessment of this factor would justify a topical study.

The service offered by Maglev being superior, it is natural that the ticket cost should be higher. But is the Maglev service 160% superior? Only the market success would tell and any a priori assessment would be highly speculative. It should be observed, however, that Maglev, being an "up-to-date" technology would have, due to its very newness, a market appeal greater that could be explained by its level-of-service qualities, which are high. This market appeal, which is not reflected in the traffic forecasts presented in this study (as they are based primarily on observed elasticities to travel time), would naturally command a premium on the ticket cost.

This does not imply that the shorter travel time and newness together justify a 60% premium vis-a-vis Rail. But it can be observed that business travelers, which are not price-sensitive, are certainly status-attracted: how else could one explain the high usage of air travel in the U.S. Northeast Corridor, where train often offers a shorter travel time. That "sophiticated" aspect would also favour Maglev.

7.7 System Optimization

Basic systems discussed to this point are over-designed to a certain degree, as neither a double track nor a double guideway is either required or warranted for the Montreal - Ottawa traffic alone.

This systematic overdesign was necessary to identify all the terrain difficulties that would have an impact on construction costs. Indeed, these difficulties must be resolved even when only a limited system is built, to provide a capability for future expansion.

To negate the effect of that overdesign, a single-track Rail system and a single-guideway Maglev system were analyzed, with the same traffic forecasts and performance specifications as the (double-track and double guideway) basic systems.

7.7.1 Single-track Rail System

This system will now be briefly described, sub-system by sub-system. Only the differences with the basic system will be noted; this will be done in the same order as in Table 7-3.

As the traffic does not change and the schedule remains the same, the same fleet of cars will be required and its cost will be the same as for the basic system.

The full right-of-way required for the ultimate system will be acquired at the outset, as is usually done to avoid future problems. Accordingly, the optimized Rail system will have the same land acquisition cost as the basic system.

As for earthwork, which is very complicated to do near a system in operation, a complete double roadbed will be prepared: the optimized system will have the same site preparation cost as the basic system.

Track foundation is required only where a track will effectively be required. The basic system required 418,8 km of (single) track: double track over a 185,0 km route, 28,9 km of freight track, and 5% extra. The optimized system will thus require only 297,0 km of single track, as follows:

- 185 km of single track along the complete route, and a second track only as follows:
- 23 km on Montreal Island for operational flexibility,
- 6 km in Mirabel Spur,
- 20 km for a meet section near Ottawa River,
- 20 km for a meet section near Ottawa,
- 28,9 km of freight track;
- 14,1 km of extra track (5%).

The track schematic and corresponding turnout list were adjusted accordingly. Cost for work for foundation through track laying was reduced in proportion to track length.

All grade separation structures would be built at the outset, except that existing highway overpasses, which already have a provision for at least one additional track, would not have to be rebuilt.

All short bridges and culverts would be built for a double track, as would the Ottawa River Bridge. As bridges across the Rivières des Prairies and Rivière des Mille Iles were designed as separate structures in the basic system (a 3-track bridge along a 2-track bridge), only the narrower structures would be built for the optimized system. Bridge construction costs were reduced accordingly.

Power supply would be as for the basic system, but the catenary would be in proportion to the reduced track length and signalling also designed for the new track layout. Communications would not change. Neither would stations or maintenance building and equipment costs.

Investment costs for the optimized single-track Rail system are given in Table 7-15.

As for recurring costs, only maintenance costs would change, as the service remains the same in all respects as with the basic double-track system. Roadway and structure maintenance costs would be reduced to 68% of their value in the base case and power and control maintenance costs, to 79% of their base value. Maintenance administration costs would also be reduced proportionately.

Financial analysis of the optimized single-track Rail system shows that the ticket cost for single-track Rail is $50.48 when averaged out over a twenty-year project life: this is 89% of the base cost for a double-track system.

7.7.2 Single-Guideway Maglev System

As in the case of the optimized Rail system, the traffic, the schedule, and the fleet of cars are the same for the single-guideway Maglev as for the double-guideway basic Maglev.

The full right-of-way would be acquired at the outset in expectation of a future double-guideway system. Site preparation costs would be the same as for the basic system. Most other system elements would vary with guideway length.

To estimate the revised construction costs of the reduced-length guideway and its equipment, it is necessary to determine the length of any stretch where the guideway must remain double to allow a (preferably) full-speed meet between Maglev consists traveling in opposite directions.

As the travel time is 45 min and the minimum interval is also 45 min, there is, strictly speaking, only a single meet along the route: it occurs 22,5 min after opposite Maglev trains have left their respective terminals. As the average speed between Ottawa and Mirabel is approximately 360 km/h, the meet occurs approximately 135 km from Ottawa, that is at km 55, which is 2 km after leaving Mirabel for Ottawa. There should be a double-guideway section of 25 km in that area, where the guideway is built with a 5 m clearance above the terrain.

In theory, each train would arrive at a terminal exactly when the opposite train departs and a single guideway would suffice; in case of slips in schedules, the guideway should be double for 5 km near each terminal. Such a guideway layout would require one high-speed turnout and five low-speed turnouts on the route, including workshop, plus four low- speed turnouts for emergency sidings.

In the basic system, the double guideway was configured at 0 m for 8,9 km, at 2 m for 6,4 km, at 5 m for 152,3 km, over 2 tracks for 16,2 km and over 3 tracks for 5,7 km, for a total (single guideway) length of 379,0 km. In the optimized system, the following lengths of single guideway would be built: 0 m for 8,9 km (plus doubling for 5,0 km near Ottawa); 2 m for 6,4 km; 5 m for 152,3 km (plus doubling for 25,0 km near Mirabel). Over railways, the frame would be built for double tracks, but the beam would be single except for 5 km near Windsor Station for a total (single guideway) length of 224,5 km. The guideway construction costs have been adjusted accordingly.

Table 7-15

Comparative Capital Costs for Single-Track / Guideway Systems

SECTION Item	Capital Costs (CDN $M 1983)				Cost Ratio (Maglev/Rail)	
	Rail		Maglev			
VEHICLES						
Sub-Total	94,5	(94,5)	111,5	(111,5)	1,18	(1,18)
INFRASTRUCTURE						
Land Acquisition	2,6	(2,6)	12,2	(12,2)	4,69	(4,69)
Site Preparation	53,3	(53,3)	19,4	(19,4)	0,36	(0,36)
Foundations	59,3	(83,6)	104,3	(179,3)	2,37	(2,14)
Piers	-	-	40,2	(68,7)	-	-
Guideway Beams	-	-	220,0	(379,0)	-	-
Guideway Bearings	-	-	9,0	(15,2)	-	-
Grade Separations	35,4	(39,7)	-	-	-	- -
Special Structures	44,6	(44,6)	47,6	(47,6)	1,07	(1,07)
River and Stream Crossings	51,4	(72,5)	6,3	(6,3)	0,12	(0,09)
Track / Guidance Rails	84,8	(113,3)	63,9	(108,3)	0,75	(0,97)
Turnouts	9,2	(14,3)	18,9	(30,1)	2,05	(2,10)
Sub-Total	340,6	(423,9)	541,8	(866,2)	1,68	(2,01)
POWER AND CONTROL						
Power Supply	3,3	(3,3)	97,7	(168,5)	47,22	(80,03)
Power Distribution	27,5	(38,9)	124,3	(210,7)	5,34	(6,21)
Signalling	33,9	(41,1)	56,0	(96,6)	1,91	(2,66)
Communications	3,5	(3,5)	3,5	(3,5)	1,00	(1,00)
Sub-Total	68,2	(86,8)	281,5	(479,3)	5,43	(7,12)
FACILITIES						
Stations	3,1	(3,1)	7,2	(7,2)	2,29	(2,29)
Maintenance Building	4,5	(4,5)	4,5	(4,5)	1,00	(1,00)
Maintenance Equipement	5,5	(5,5)	5,5	(5,5)	1,00	(1,00)
Sub-Total	13,1	(13,1)	17,2	(17,2)	1,31	(1,31)
TOTAL DIRECT CAPITAL COST	516,4	(618,3)	952,0	(1474,2)	2,07	(2,58)
Legal Fees	2,6	(2,6)	12,2	(12,3)	4,69	(4,69)
Design (1%)	5,2	(6,2)	9,5	(14,7)	2,06	(2,58)
Engineering (4%)	20,6	(24,7)	38,1	(59,0)	2,08	(2,58)
Construction Management (4%)	20,6	(24,7)	38,1	(59,0)	2,08	(2,58)
Sub-Total	49,0	(58,2)	101,8	(145,0)	2,21	(2,68)
TOTAL CAPITAL COST	564,6	(676,5)	1095,8	(1619,1)	2,08	(2,59)

All guideway-mounted equipment was laid along 193,3 km of double guideway in the basic Maglev system; on the optimized system, it would be built along a total length of 228,3 km of single guideway (59% of the length of the basic system) and all relevant costs adjusted accordingly, including: beams, bearings guidance rails, long stator, power supply, power distribution, signalling. Communications and auxiliary equipment costs would not change, neither would stations'.

Investment costs for the optimized single-guideway Maglev system are given in Table 7-15. As for recurring costs, only those for maintenance of fixed equipment would change: infrastructure maintenance costs will be reduced to 68% of their value in the basic system and power and control maintenance costs to 59%. Maintenance administration costs will be reduced in proportion.

Financial analysis of the optimized single-guideway Maglev system shows that the ticket cost, averaged over a twenty-year project life, amounts to $77.23: this is 77% of the ticket cost for a double-guideway system.

When comparing the two optimized systems, it appear that the ratio of ticket costs has changed: the ratio of Maglev to Rail is 153%, where as it was 178% for basic systems. This implies that the Maglev optimization was more effective. In other words, there was a greater amount of overdesign in the double-guideway Maglev system than in the double-track Rail system.

This is also partly related to technology: due to its greater speed, the Maglev requires only one section of double guideway for meets. The slower Rail system requires two sections, and longer ones at that.

8. IMPACT EVALUATION

The objective of this chapter is to discuss and evaluate impacts resulting from the implementation and operation of a Rail or Maglev system.

The primary intent of this evaluation is not to compare the situation before and after the commissioning on one of the two systems: this would be the appropriate focus when discussing whether construction of a system is beneficial or not, justified or not. As the present study is concerned with comparing two technologies, the evaluation of impacts that follows is designed to identify and evaluate the differences between both systems with respect to their impacts. Its method is described in the first section of the chapter.

For evaluation purposes, impacts have been organized in classes reflecting different groups on which they are exerted and/or whether the impact results from the presence, construction, or operation of the system; these classes are as follows:

- technical risks: temporary impacts exerted primarily before system commissioning and having a possibly significant influence on its commercial success;
- energy and traffic impacts, which are a direct consequence of the system technology and, in turn, generate indirect impacts;
- employment impacts, most of which are temporary and are exerted during construction only;
- social and economic impacts: on-going indirect impacts resulting from the energy and traffic impacts of the system;
- aesthetic and environmental impacts: long-term indirect impacts resulting from the mere presence of the system and generally compounded by the intensity of its operation.

Technical risks associated with placing and maintaining the system in operation are discussed in the second section of the chapter. They are primarily a concern of the agency responsible for commisionning the system and, to a lesser degree, an on-going concern of the operator. If the risks are too great and the system can not be operated reliably, then all other impacts will be felt to a substantially lesser degree. In that sense, technical risks are a threshold impact.

Energy and traffic impacts are a direct result of the success of the system. Energy will be consumed for the operation of the system but also for its construction. Traffic impacts will be felt first by traveler using the HSGT and eventually by travelers switching to HSGT from other modes (and ultimately by the operators of these modes if they are public). These issues are discussed in the third section of the chapter.

Employment impacts are discussed in the fourth section. A large number of temporary jobs will be created for building the fixed facilities for the system and for manufacturing its rolling stock and the mechanical, electrical, and electronic components of the power and control equipment; manufacturing employment impacts will inherently be related to the Canadian content. Permanent jobs will be created for operating the system.

Social and economic impacts of different types will be exerted progressively over time as a result of changes in travel behavior and in relative accessibility: stimulation of various activities and changes in land use, etc. These impacts, functional in nature, are likely to have long-lasting and possibly irreversible effects; they could not be analyzed in depth within the scope of the study.

Aesthetic and environmental impacts, which are physical rather than functional in nature, will be permanent. Their effects will be felt primarily by the neighbours of the system, humans and animals. These impacts are discussed in the fifth and last section in the chapter.

8.1 Evaluation Methodology

The objectives of this evaluation are quite different from those of a conventional impact analysis, where one often wants to determine whether the impacts of a proposed system (usually felt primarily by non-users) are commensurate with its benefits (often accruing mainly to users of the system) and whether, as a result, the system will be socially acceptable and/or economically justifiable or not. In those cases, the reference for comparison is clearly the present situation and the focus is on how much it is changed.

The present evaluation, rather than demonstrating the acceptability of a new system, must contribute to the prime objective of the study, which is the identification of the significant distinctions in impacts between two differents technologies fulfilling essentially similar missions.

As a result, the evaluation will emphasize the nature of the various impacts and assess their degree, by comparison between the Rail and Maglev systems, rather than strive for a quantitive evaluation of their precise level, as this would require in-depth investigations that are clearly beyond the scope of the present study.

As a consequence, no definite conclusion will be derivable from the impact evaluation as to whether the proposed Rail and Maglev Systems could be socially acceptable or economically justifiable.

8.2 Technical Risk Evaluation

Technical risks associated with the introduction of new technology are a serious concern for transportation planners and decision-makers.

As a result of a small number of greatly over-publicized "teething pains", BART being the most famous example, the general (and perhaps candid) infatuation with new systems that characterized the early 1970's (one only has to remember the immense success of Transpo 72) has been replaced by systematic suspicion about new technology and constant resort to "new but proven" technology.

As a result, the instinctive reaction to the mention of Maglev as a candidate system is, too often: "But it is not a proven system". This only stresses the importance of addressing squarely the issues associated with the numerous technological innovations offered by the Maglev system.

In Canada, two key issues are most often associated with the introduction of new technology from another country: the technical imponderables ("Will the system work or is there still a great amount of developement? Can the costs be predicted with a reasonable degree of confidence?") and the problems associated with winter operation (it often took 5 years or more to thoroughly adapt a well-proven automobile design to winter operation in Canada).

8.2.1 Technical imponderables

There are few technical imponderables associated with the service introduction of an electrified Rail system with a 200 km/h maximum speed. Depending on the source design, some technical components might have to be changed to adapt to Canadian legislation or maintenance practices.

In the case of Maglev, the major imponderable is that the TRANSRAPID 06 vehicle, which has reached at 305 km/h at Emsland, has been operated in demonstration service only. Other research vehicles using the magnetic levitation technology have been operated at speeds exceeding 400 km/h.

Also, the major system components for the Maglev system (vehicle, guideway, and power supply) have been designed and manufactured following a long period of research and development. Most components have been subjected to comprehensive qualification testing and regulatory authorities were involved in the project from the beginning to facilitate securing the necessary safety approvals.

Numerous techncal problems have thus been resolved during the development period. Still, as a long stator Maglev system of the size and power of the TR 06 has never been demonstrated under service-like conditions, other problems will be found during testing that are not even known now.

In summary, Maglev, involves more technical imponderables than Rail. As a result of the rigorous demonstration testing to be conducted at the Emsland Test Facility over the next several years, new problems will be discovered and, eventually, resolved. At the end of these tests, several desirable improvements ot the Maglev design may have been identified, developed, and, in some cases, introduced into the prototype system. The Maglev technology will then be ready for revenue testing.

From this, it can be concluded that service introduction of a Maglev system in Canada in 1991 appears premature, unless as a result of a specific policy decision which would accelerate the testing of the system.

8.2.2 Winter Operation

Winter operation has always been a problem for transporation vehicles in Canada. This historical fact has tended to create an automatic intuitive reaction that any new vehicle is not suitable for winter operation and must be redesigned to a significant degree.

For instance, in the Great North, road and snow vehicles and piston-engined aircraft have had to be kept in continuous operation to prevent engine freezing; conventional hydraulic systems fail to operate in winter (the author has seen gasoline used as a hydraulic fluid in a carrier vehicle). But, as with private automobiles, the major problem is often to restart a vehicle that has been left too long in the cold wind.

HSGT operation between Montreal and Ottawa would very seldom involve ambient temperatures below -30°C over long periods (-25°C for two or three days every winter is more typical). The major problem is likely to be related to sleet or freezing rain, mainly in November and December. The presence of such a large body of water as the St-Lawrence River intensifies sleet formation around Montreal: precipitations that would fall as snow elsewhere are heated by low-level warm air banks created by the river, then freeze upon touching the cold ground.

Whether for Rail or Maglev, the high frequency of service and long hours of operation will contribute to alleviate the negative impacts of winter conditions. In a similar fashion, by operating 24 h/day at 15-min. intervals, the elevated transit system in Chicago has been able to operate continuously through hard winters, being stopped by snow reputedly only very rarely.

For Rail, the major winter problems are related to maintaining turnouts in operating order. This will be solved by installing switch heaters at every turnout: these machines, started automatically below a certain temperature or actuated from central control, will prevent the accumulation and packing of snow or the formation of ice between switch blades. Sleet formation on tracks is not a major problem, as the high pressure exerted by steel wheels on the rail will crack the sleet or ice(1). Also, as tracks are built somewhat above the terrain, cross winds will blow the snow off the tracks, preventing the accumulation of snow banks. Ice formation on the catenary could be a significant problem; it would be alleviated by running trains all night at frequent intervals when weather conditions favour ice formation on the wires. Catenary designs would have to take into account the extra weight of sleet and the experience gained in Northern Quebec and in Scandinavia.

In the case of Maglev, limited experience only was obtained from previous test vehicles and test tracks, which were not operated significantly under winter conditions. At the Emsland Test Facility, a special vehicle, equipped with a snow plow and rotating brushes, will be used to remove soft snow from the guideway surface.

The formation of ice or the packing of snow on the guideway could be a serious problem, as the clearance between the carbody and the guideway surface is in the order of 100 mm only. The use of chemicals to melt ice or packed snow is presently envisioned; given the length of the route between Montreal and Ottawa, however, the cost of using non-corrosive chemicals would probably be prohibitive; the same applies to the use of electricity. The best strategy would then be to operate the system frequently all night when conditions warrant it.

Concerning very cold weather, the Maglev system is designed to operate without any restriction at temperatures down to -25°C. At temperatures between -25°C and -40°C, operational restriction would aply and the operation might have to be shut down. System operation below -55°C is not envisioned.

8.3 Energy Impacts

The objective of this section is to identify the major differences between the Rail and Maglev systems as to their use of energy for system operation and implementation. Both systems will indeed consume significant amounts of energy every year for their operation (for propulsion and other operational purposes) and their maintenance. Their manufacturing and construction will also require important amounts of energy.

By attracting passengers from other modes (air, bus and auto), both HSGT systems would exert noticeable impacts on intercity modal split. These modal shifts will in turn exert energy impacts that will generally be favourable.

8.3.1 Energy Requirements

In this brief analysis, energy requirements of the Rail and Maglev systems will be classified according to their type, following the usual categories of direct and indirect energy.

According to that classification, only energy used for vehicle propulsion is considered as direct energy.

By contrast, indirect energy is that which is used for one of the following purposes:

- operations, except vehicle propulsion (heating and lighting stations, for instance);
- vehicle and infrastructure maintenance;
- the production of direct energy (for instance, energy losses when using oil or coal to produce electricity for vehicle propulsion);
- vehicle and component manufacturing;
- structure and infrastructure construction.

From the above, it is obvious that some indirect energy will be consumed annually for system operation and maintenance, and some more, once and for all upon implementation. That subdivison will be used below.

8.3.2 Consumption of Direct Energy

Power supply and energy consumption volumes and charges were discussed in Sections 5.11 for Rail and 6.13 for Maglev.

Based on the formula given in Section 5.11, the Rail system would consume 117 173 GJ/year for vehicle propulsion from 1991, at a cost of $511 000. In 1999, the annual consumption would increase by 20% as a result of the addition of a fifth car to each consist.

Based on the formula given in Section 6.13, the Maglev system would consume 231 592 GJ/year of electrical energy for vehicle propulsion, at a cost of $1 010 000/year. This annual consumption would increase by 33% in 1993 and by 20% in 1999 as a result of the introduction of additional intermediate sections in all Maglev consists.

8.3.3 Annual Consumption of Indirect Energy

In addition to what is required for vehicle propulsion, some energy will be consumed every year for operating the system and for maintaining it.

Non-propulsion operating energy can be estimated as a proportion of direct energy. Thirty percent has been used in some studies and will be adopted here: both systems will be assumed to consume, for their operation, 30% of the Rail propulsion energy, that is 35 152 GJ/year. Even if it consumed more energy for propulsion, the Maglev system can be assumed as not consuming more energy than Rail for such purposes as heating stations and powering switches and the signalling system.

Energy consumption for maintenance can be estimated using the observed relationship between maintenance expenditures and energy consumption. In a study on indirect energy in transportation (4), the consumption of energy for maintenance was estimated from a survey of existing transportation systems. The relevant results, expressed in British Thermal Units (BTU) per 1966 Canadian Dollar, are the following:

- vehicle maintenance	35 000 BTU/$
- infrastructure maintenance, heavy system	40 000 BTU/$
- infrastructure maintenance, light system	20 000 BTU/$

Using a conversion factor of 1,055 kJ/BTU and a 1983/1966 labour cost index of 4,73, the above parameters become:

- vehicle maintenance	7 807 MJ/$
- infrastructure maintenance, heavy system	8 922 MJ/$
- infrastructure maintenance, light system	4 461 MJ/$

Values for a heavy system can be used for the Rail system, while values for a light system can be used for the Maglev system, which probably has higher labour costs for maintenance as a results of using more specialzed manpower for its more advanced technology.

Based on estimated maintenance costs (Table 7-6) and the above parameters, the Rail system would consume 100 485 GJ/year for maintenance in 1991 and the Maglev system, 111 114 GJ/year.

Energy consumed recurringly for other purposes will be ignored. For instance, it will be presumed that no energy will be lost in producing direct energy. This is a reasonable assumption as, in Quebec, all electricity is of hydraulic origin (except in a few isolated islands or remote loctions). Energy supply in the eastern part of Ontario is also of hydraulic origin.

Annual energy consumption by component is given in Table 8-1.

Table 8-1

Annual Energy Consumption Estimates

Use of Energy	Annual Consumption (MJ/year, 1991)	
	Rail	Maglev
VEHICLE PROPULSION	117 173	231 592
SYSTEM OPERATION	35 152	35 152
Sub-Total Operation	152 325	266 744
VEHICLE MAINTENANCE	41 560	40 674
SYSTEM MAINTENANCE	51 925	70 440
Sub-Total Maintenance	100 485	111 114
TOTAL	252 810	377 858

8.3.4 One-Time Consumption of Indirect Energy

The same reference (4) provides data on energy consumption of construction and manufacturing activities in the transportation system sector. That data is shown in the second column of Table 8-2.

To be used in the present study, that data was converted to SI units using appropriate conversion factors and updated to 1983 using appropriate construction or manufacturing cost indices. The result is shown in the third column of Table 8-2.

Using the capital costs of both systems appearing in Table 7-3, it then becomes a simple matter of multiplication to obtain estimates of the energy consumption for manufacturing and construction of the Rail and Maglev systems. Naturally, the result is dependent upon the validity of the base data from Reference 4.

When estimating energy consumption for vehicle manufacturing, the following assumptions were made. A Rail vehicle was presumed to be 35% locomotive and 65% railcar by cost, given its manufacturing techniques. Similarly, a Maglev vehicle was presumed to be 40% aircraft and 60% railcar by cost.

The results are shown in Table 8-3. One notes that the Maglev/Rail ratio of indirect energy construction for manufacturing and construction (182,5%) is not quite as high as the ratio of capital costs (239,2%). This is because, using more advanced technology, Maglev requires more specialized (hence more expensive) labour for its construction, resulting in a decrease in the relative importance of energy. In total, however, Maglev requires almost twice as much energy as Rail does.

Table 8-2

Base Data for Indirect Energy Consumption

Sub-system or Activity	Original Data (1) BTU/$ (date)	Modified Data (2,3) (MJ/$-1983)
Locomotive Manufacturing	30 000 (1974)	14,00
Railcar Manufacturing	20 000 (1974)	9,33
Aircraft Manufacturing	15 000 (1974)	7,00
Rail Vehicle Manufacturing (4)	-	10,97
Maglev Vehicle Manufacturing (5)	-	8,40
Infrastructure Construction	153 000 (1966)	37,54
Structure Construction	52 200 (1966)	12,81
Electrical Equipment Manufacturing (Industrial)	10 000 (1974)	4,67

Notes: 1. The original data is from Reference 4.
2. The following cost index ratios were used: 1983/1966: 4,30
1983/1974: 2,26.
3. One BTU is equivalent to 1,055 kJ.
4. A Rail vehicle is 35% locomotive, 65% railcar by cost.
5. A Maglev vehicle is 40% aircraft, 60% railcar by cost.

Table 8-3

Indirect Energy for Manufacturing and Construction

Sub-system	Rail System		Maglev System	
	Cost (1983 M$)	Energy (GJ)	Cost (1983 M$)	Energy (GJ)
VEHICLE				
Direct Capital Cost	94,5		111,5	
DEPCM (9%)	8,5		10,0	
Sub-Total	103,0	1129910	121,5	1020894
INFRASTRUCTURE				
Direct Capital Cost	267,1		418,0	
DEPCM (9%)	26,6		49,8	
Sub-Total	293,7	11025498	467,8	17561963
STRUCTURE				
Direct Capital Cost	156,8		448,1	
DEPCM (9%)	14,1		40,3	
Sub-Total	170,9	2189382	488,4	6256775
POWER AND CONTROL EQUIPMENT				
Direct Capital Cost	86,8		479,1	
DEPCM (9%)	7,8		43,1	
Sub-Total	94,6	441782	522,2	2437629
FACILITIES				
Direct Capital Cost	13,1		17,1	
DEPCM (9%)	1,2		1,5	
Sub-Total	14,3	536822	18,6	698244
TOTAL	676,5	15323394	1618,5	27975505

Notes:
1. Capital costs for both systems are given in Table 7-3.
2. DEPCM, meaning "Design, Engineering, Procurements, and Construction Management", is equivalent to 9% of direct capital costs.
3. Legal fees are added to the DEPCM for Infrastructure.
4. Indirect energy consumption factors are given in Table 8-2.

8.4 Employment Impacts

Two types of employment will be created as a result of the decision to implement a HSGT system between Montreal and Ottawa: "permanent" jobs related to the system's operation and maintenance, and temporary jobs related to its design, engineering, and construction.

8.4.1 Permanent Employment for System Operation

Permanent jobs will be created for operating and maintaining the system. Operation jobs will be related to the operation of trains and stations, the provision of reservation services, and system supervision from the control center. Maintenance jobs can be classified as related to vehicle, infrastructure, electrical systems, signalling, and other. Administrative support will need to be provided, and this will create additional administrative employment.

The nature and responsibilities of the jobs mentionned above was discussed in greater detail when explaining the evaluation of operating and maintenance costs. Details can be found in Sections 5.9 and 5.10 for Rail, and 6.11 and 6.12 for Maglev.

Table 8-4 provides a comparative listing of permanent jobs created by both systems. Operation staff was enumerated in Tables 5-14 for Rail and 6-20 for Maglev. Maintenance costs were not estimated by evaluating the number of positions and the staff requirements, but by reference with observed costs or by direct estimation. To estimate a posteriori the number of maintenance jobs, the estimated maintenance cost for each item was divided by the appropriate salary costs.

First however, as it includes clerical and supervision costs, which correspond to a margin of 18%, that was subtracted to obtain the amount for direct jobs. The number of indirect jobs was estimated by dividing that margin by $26 000, the annual salary cost for clerical personnel appearing in Tables 5-11 and 6-17.

The remaining amount for direct maintenance jobs was divided by $29 000 or $34 800 depending on whether for Rail or Maglev. According to Table 5-11 and 6-17, $29 000 is the annual salary cost of a maintenance agent; a technology premium, of 20% has been added for Maglev reflects the additional qualifications required to maintain its more complex equipment.

For administration costs, an annual salary cost of $45 000 was used as an average for the variety of personnel involved, from clerical to presidential. The administrative costs are as given in Table 7-7.

As one would expect, the Maglev system, which has higher maintenance costs (chiefly due to its technology), exerting a significance influence on total annual costs, creates a larger number of permanent jobs, 1130 as opposed to 889 for Rail.

8.4.2 Temporary Employment for System Implementation

Employment creation as a result of major governmental projects has become an increasingly important political and social concern over the last several years in Canada, as governments were expected to reactivate a slowing economy.

Partly as a result of this situation, industrial impact analyses became increasingly sophisticated in their methods, sometimes basing their evaluations on input-output matrices of a provincial or regional economy. Such detailed analyses are clearly beyond the scope of the present study; consequently, the results presented below should by no means be considered definitive, but only an indication of the relative effects of Rail and Maglev.

Table 8-4

Comparative Evaluation of Permanent Employment Creation

Sector	Permanent Employment Created (1991)	
	Rail	Maglev
TRAIN CREWS		
Enginemen/Pilots	42	20
Conductors	25	20
Stewards	100	60
Indirect Employments	43	30
Sub-Total	210	130
STATION OPERATION		
Management	10	10
Administration	32	32
Ticket Agents	54	82
Other	56	56
Sub-Total	152	180
RESERVATION	27	34
SYSTEM SUPERVISION		
Management/Clerical	3	3
Terminal Supervision	15	10
Dispatchers	10	10
Operators	10	10
Sub-Total	38	33
SUB-TOTAL FOR OPERATION	**427**	**377**
VEHICLES MAINTENANCE		
Direct Employments	182	129
Indirect Employements	36	31
Sub-Total	218	160
TRACK AND STRUCTURE MAINTENANCE		
Direct Employments	78	114
Indirect Employments	16	27
Sub-Total	94	141
ELECTRICAL MAINTENANCE		
Direct Employments	22	241
Indirect Employments	4	58
Sub-Total	26	299
SIGNALLING MAINTENANCE & OTHER		
Direct Employments	70	86
Indirect Employments	14	21
Sub-Total	84	107
SUB-TOTAL FOR MAINTENANCE	**422**	**707**
ADMINISTRATION	**40**	**46**
TOTAL	889	1 130

The present evaluation relies heavily on two recent references: a detailed economic impact analyses of a projected surface transit line in Montreal (1) and a study of the industrial impact of rolling stock and railway equipment procurement for the Quebec-Windsor Corridor (2). The first of these studies is very detailed and considers all sub-systems including civil works, but deals with an urban transit project while the second, although less detailed and less comprehensive, deals specifically with HSGT systems.

Temporary employment creation was evaluated as follows:

- starting with capital cost estimates (from Table 7-3);

- identify a Canadian content (based primarily on Reference 2);

- use an average rate for direct employment creation per dollar invested presented as a result in the above studies (Reference 1 for infrastructure, Reference 2 for rolling stock, equipment, and engineering);

- evaluate direct employment, and then indirect employment by multiplication.

Such a simplified method is, evidently, highly sensitive to the value of the two prime input parameters, Canadian content and the unit cost of creating one direct job. Results are presented in Tables 8-5, and 8-6; a column in these tables coresponds to every step in the method given above. As one would expect, Maglev creates more employment in total and slightly less employment per dollar invested. This is on account of its slightly inferior Canadian content and higher salaries for more qualified personnel.

Table 8-5

Evaluation of Temporary Employment Creation by Rail

Sector Item	Capital Cost ($M,1983)	Canadian Content (%)	Employment Creation Rate (person-year per $M invested)	Employment Creation (person-years)	
				Direct	Total
VEHICLES					
Sub-Total	94,5	75	0,0	680	1 293
INFRASTRUCTURE					
Land Acquisition	2,6	100	12,4	0	0
Site Preparation	53,3	100	12,4	661	1 255
Track Foundations	83,6	100	12,4	1 037	1 970
Structures	156,8	95	12,4	1 847	3 509
Tracks	113,3	95	12,4	1 335	2 536
Turnouts	14,3	70		124	236
Sub-Total	423,9			5 004	9 506
POWER AND CONTROL					
Power Supply	3,3	95	17,6	55	105
Power Distribution	38,9	60	17,6	411	780
Wayside Signals	36,6	75	17,6	45	85
Control Center	4,5	80	17,6	63	120
Communications	3,5	90	17,6	55	105
Sub-Total	86,8			629	1 195
FACILITIES					
Stations & Building	7,6	100	12,4	94	179
Maintenance Equipment	5,5	70	9,6	37	70
Sub-Total	13,1			131	244
DESIGN, ENGINEERING and LEGAL					
Sub-Total	33,5	80	11,0	295	560
CONSTRUCTION MANAGEMENT					
Sub-Total	24,7	95	10,8	253	482
TOTAL	676,5	-	-	6 992	13 280

Table 8-6

Preliminary Evaluation of Temporary Employment Creation by Maglev

Sector Item	Capital Cost ($M,1983)	Canadian Content (%)	Employment Creation Rate (person-year per $M invested)	Employment Creation (person-years)	
				Direct	Total
VEHICLES					
Sub-Total	111,5	70	9,6	749	1 424
INFRASTRUCTURE					
Land Acquisition	12,3	100	0	0	0
Site Preparation	19,4	100	12,4	241	457
Foundations	179,3	100	12,4	2 223	4 224
Piers	68,7	100	12,4	852	1 619
Beams	379,0	95	12,4	4 465	8 483
Bearings	15,2	50	12,4	94	179
Structures & other	53,9	100	12,4	668	1 270
Rails	108,3	90	12,4	1 209	2 296
Turnouts	30,1	70	12,4	261	496
Sub-Total	866,2	95,4	12,2	10 013	19 024
POWER AND CONTROL					
Power Supply	168,5	80	17,6	2 795	5 310
Power Distribution	210,7	60	17,6	2 225	4 228
Signalling	96,6	70	17,6	1 190	2 261
Communications	3,5	90	17,6	55	105
Sub-Total	479,3	70,5	17,6	6 265	11 904
FACILITIES					
Stations & Building	11,7	100	12,4	144	273
Maintenance Equipment	5,5	65	9,6	34	65
Sub-Total	17,2	88,7	11,7	178	338
DESIGN, ENGINEERING and LEGAL					
Sub-Total	86,0	75	11,0	708	1 348
CONSTRUCTION MANAGEMENT				573	1 090
Sub-Total	59,0	90	10,8		
TOTAL	1 619,1	-	13,5	18 486	35 728

8.5 Aesthetic and Environmental Impacts

These physical impacts result directly from the mere presence of the system and/or are associated with its operation, in which case they are often proportional to the volume of traffic and the intensiveness of the operation.

Aesthetic and environmental impacts are usually negative; they are felt by people residing or working near the system and some forms of life can be affected by them. As these physical impacts too often cause irreparable damage, nowadays their nature and level are scrutinized before a new system can be considered socially acceptable. In the U.S.A., the Urban Mass Transportation Administration (UMTA) requires a formal impact analysis before funding the construction of a new transit system. The classification of physical impacts in this study is inspired by the framework prescribed by UMTA for conducting the required impact analysis.

8.5.1 Noise

Several factors contribute to people's reaction to the noise impacts from a new transportation system. Amongst these factors, are:

- the type of noise, which results from the technical configuration of the system;
- the sound level, which results from the vehicle speed and the curviness of the alignment;
- the frequency of passage of the vehicles, which directly increases the disturbance effect;
- the ambient noise level, through which operation of the vehicle may or may not be distinguishable.

To this must be added the fact that people are nowadays highly sensitive about expected noise impacts. Being somewhat apprehensive as a result, they are likely to be more negative about a new type of system with unknown noise characteristics, such as Maglev.

Major sources of noise in guided ground transport vehicles are the engine, the running gear, and the carbody, which produces aerodynamic noise resulting from skin friction. Engine noise is naturally greatest with internal combustion engines; it will not be a factor in this case. Running gear noise is related to the design, construction, age, and state of maintenance of the wheels, trucks, and track, as well as to the number and severity of horizontal curves in the alignment; due to its contact-less guidance, levitation, and propulsion systems, the Maglev system produces no running gear noise. Aerodynamic noise is related to speed and to the design and quality of the surface finish of the carbody; it is expected to be greater for Maglev due to its greater speed.

The expected sound levels for both systems were evaluated using the equivalent sound level measured at 25 m from the track for the expected frequency of service. In noisy parts of urban areas, such as Montreal and Ottawa downtown, the ambient noise level is in the order of 65 dB(A). As both systems travel at low speed near the terminals, they would exert practically no noticeable noise impact.

Away from downtown, in what could be qualified as "normal" urban neighborhoods, both systems would travel faster, but their speed would still be limited: in the case of Rail, to 160 km/h due to the alignment; in the case of Maglev, to 200 km/h, precisely to present excessive noise. In the absence of running gear and aerodynamic noises, the Maglev would have practically no impact. Due to running gear noise and curves, the Rail system would exert a moderate noise impact: between 3 and 6 dB(A) above the ambient noise level.

To determine the social acceptability of either system with respect to noise in urban areas, a detailed analysis would need to be conducted to take into account local conditions along the route. It is not expected that major problems would effectively be encountered.

In rural areas, each system will cruise at its maximum operating speed: 200 km/h for Rail and 400 km/h for Maglev. As aerodynamic noise will be prevalent, Maglev will exert greater noise impacts. As the intensity of sound decreases with the squared inverse of the distance, and since both systems pass near houses only occasionnally in rural areas, their actual noise impact would probably not be significant.

This is not to say, however, that noise impacts would not become a major public issue: it probably would receive considerable attention (quite in proportion to the level of investment!) Being better known, Rail would probably benefit from a more favorable subjective judgement by the public.

8.5.2 Visual Intrusion

Visual impacts resulting from the implementation of the Rail system will be minimal as it uses existing railways for 60% of its route and is built at grade on all of its alignement.

Maglev, by contrast, would be judged by the public as having a very significant visual impact, since it uses an elevated guideway for a great portion of its route: 80% is built on a guideway with a 5 m clearance while 9% is built on a still higher guideway, 9 m above railway tracks.

There will be no problem around Ottawa, as the Maglev route is at grade there. In Montreal, however, the situation with be quite different, as there is an almost universal ban (public as well as political) on overhead structures. As a result, the proposal of building an elevated guideway could generate a great public outcry despite the fact that, in some areas, the actual visual impact could actually negligible and perhaps could even be judged positive: this is the case for the roule selected, which parallels an elevated expressway near downtown Montreal.

8.5.3 Environmental Insertion of HSGT Rights-of-Way

From the comments above, it appears that most physical impact (noise, visual intrusion) and some functional impacts (community disruption, for instance) are directly related to the presence of the right-of-way and infrastructure used for operating HSGT systems: the mere presence of the facility consumes space that could be used for other purposes, creates a physical barrier, and the movement of high speed vehicles on it may be perceived as an additional source of danger.

In this study, the detailed analysis of Rail and Maglev routes on low-scale maps provided a fine opportunity to assess these effects in a variety of representative situations. The quality of the assessment was enhanced by the availability of data and previous studies, numerous site visits, and by the fact that members of the study team had substential experience with the areas studied. The following observations were made during the routing analyses.

These observations are presented below as answers to the following questions: Can it be done? How? What are the impacts? First, the possibility of using existing rights-of-way is analysed and, second, problems associated with the creation of new rights-of-way. Inferences drawn from these observations are presented separately for urban and rural areas.

The use of existing railway rights-of-way for operating HSGT services appears a promising solution: in the study area, there are numerous railway rights-of-way, and most are presently under-utilized: being 30 m in width, they typically carry one track only where there is room for five or perhaps even six.

In the case of Rail, the use of existing railways presents no major technical or operational problem. An exclusive double track for a high speed train would typically be placed on the edge of the right-of-way, on the side with the fewest industrial spurs (these could still be accessed occasionally across high speed tracks with proper protections). If there is no room for two more tracks, the high speed operation could (with possibly some level-of-service degradation) share tracks with conventional railway services for a short distance: adequate signal interlocking would ensure the safety of the joint operation.

In an urban area, the insertion of two additional tracks in an existing railway right-of-way would attract scant attention. The situation could be different in a rural area, however; it certainly would be between Montreal and Ottawa. There, existing rail lines cut across numerous farm properties. With today's almost non-existent rail traffic, farm operations are conducted as if there was no track. Frequent operation of high speed trains would change that dramatically. The right-of-way could have to be fenced, precluding uncontrolled crossing by farmers, their animals and machinery. The intrusion impact would be significant, and corrective measures (probably exensive) would have to be taken to mitigate it. These measures have been analyzed in some detail and no solution has been found that was simple, unexpensive, and satisfactory.

Inserting a Maglev guideway on an existing railway is even more difficult. Placing a double guideway at grade on the edge of the right-of-way would require approximately 15 m, consuming half of the available width. In some cases, the remaining width could be just sufficient for accomodating existing traffic and serve rail-side industries; access to one side of the right-of-way would practically be condemned.

A different solution was considered in this study: the construction of an elevated guideway above existing tracks. The guideway beams would be supported on a rigid frame designed to provide a 12 or 18 m wide clearance for railway operations. The construction of an elevated guideway creates significant visual (and possibly noise) intrusion; its construction above railway tracks may alleviate the problem, as the rail line often crosses industrial rather than residential neighborhoods.

The use of existing expressway rights-of-way was also investigated. This appears to be a good solution from the standpoint of physical impacts and disruption effects. Many North American expressways are built with a large median, which could accomodate a Rail or Maglev system.

This potentially attractive solution is not easy to implement, however. Presuming space is available in the median, most, if not all, structures crossing the median would have to be rebuilt. Drainage would have to be reorganized, as snow removal (medians are used to accumulate snow). In rural areas, this approach is probably feasible. In urban areas, however, the median is often too narrow. Access to and egress from the expressway would probably require major structural works. In this case, then, costs, rather than impacts, dominate the discussion. In the study, no expressways were found that had an appropriate alignment.

Creating a new right-of-way in an urban areas is, today, only a last resort solution, because of very high costs and strongly negative impacts. It was not found necessary to resort to that solution in the study. If it were, the guideway would probably have to be built underground. That being the case, Maglev would be at a cost disadvantage, because of the broader tunnel gauge required.

Creating a new right-of-way in a rural area presents fewer problems. Land acquisition costs are low and, due to low land use intensity, physical impacts are not a major issue. Disruption effects must be considered, however. That being the case, Maglev has an advantage in routing flexibility, as an elevated Maglev guideway does not create a physical barrier that would disrupt communities or interfere with human activities such as farming.

Summarizing, then, the insertion of HSGT guideways is likely to create unfavorable environmental impacts. These will be smallest when implementing an exclusive double track in an existing railway right-of-way in an urban area. In a rural area, depending on land use, that solution may lose much of its interest, due to the disruptive effect of the barrier created by the fenced right-of-way. Maglev guideways at grade could be implemented in existing railways under certain conditions only, but they could be built on a structure over existing tracks.

In general, the creation of new rights-of-way in a dense urban area is likely to require underground construction, in which case the Rail system would enjoy a cost advantage due to its smaller tunnel cross-section. The creation of new right-of-way in a rural area might be made more acceptable by using an elevated construction that has reduced disruptive effects; in this case, the Maglev infrastructure would present a cost advantage.

References for Chapter 8

1. Conseil des Transports de la Région de Montréal, "Etude d'impact économique du métro de surface - ligne 6" Ministère des Transports du Québec, Montréal, 1982.
2. UTDC Services Inc., "VIA Rail Canada Quebec - Windsor Corridor External Impact Study" for VIA Rail Canada, Toronto, 1983.
3. "Employment Impacts of Transit Capital Investment and Operating Expenditures" American Public Transit Association, Washington, 1983.
4. IBI Group "Indirect Energy in TRansportation" for Transport Canada, Ottawa, 1978.

9. MAJOR RESULTS AND FINDINGS

The objective of this study was to establish the major differences in costs and impacts resulting from the technological differences between two high speed guided ground transport systems, using, in one case conventional wheel-on-rail contact and, in the other case, magnetic attraction, for vehicle support, guidance, and propulsion.

The comparison was made between a Rail system with a maximum operating speed of 200 km/h, using bi-directional consists powered at 25 kV a.c. fom an overhead catenary (the "Rail" system); and the TransRapid longstator magnetic levitation system developed in the Federal Republic of Germany, with a maximum operating speed of 400 km/h (the "Maglev" system).

To lay the comparison on a firm basis in reality, conceptual designs for both systems were prepared, using a well-documented application: high speed service between Montreal and Ottawa (an airline distance of some 200 km) with two intermediate stops. Both systems were designed for the same market potential and identical service specifications. Predicted differences in estimated rideship thus resulted primarily from the travel time differential, itself due to the difference in maximum operating speeds.

This study has produced preliminary conceptual designs for these two systems.

Seen from the perspective of the passenger, the Rail system would offer 18 departures per day and a Montreal-Ottawa travel time of 70 min; that system would carry between 1,1 and 1,4 million passengers in 1991. The Maglev system would also offer 18 departures per day from each terminal, but the travel time would be 45 min; the system would carry between 1,4 and 1,8 million passengers in 1991.

Between Montreal and Ottawa, both systems would be routed along existing Railway rights-of-way wherever possible; this amounts to 62% of the route by length for Rail and 15% for Maglev. Whereas the Rail system could leave the city centre of Montreal through the Mount Royal tunnel along CN Montfort Subdivision, sharing tracks with commuter rail services, the Maglev route, by contrast, leaves the Montreal city centre along CP Vaudreuil Subdivision, the Maglev line being built on a structure above the tracks.

The Rail system is generally built at grade, but the route is in tunnels for 7,2 km in total. The Maglev system is generally built on an elevated structure, with a clearance of 5 m between the terrain and the underside of the guideway beam; this guideway configuration is used for 152,3 km. The Maglev route is built at grade for 8,9 km, with a clearance of 2 m for 6,4 km, and over tracks for 21,9 km.

The total capital cost for implementing the Rail system in 1991 amounts to $676,5 M (in 1983 Canadian dollars). The total capial cost for implementing the Maglev system is $1619,0 M. This is a Maglev/ Rail capital cost ratio of 2,39. The difference results chiefly from two factors:

- the use of a rigid structure to support the Maglev vehicles, a requirement resulting from the stringent positional tolerances needed for efficient operation of the magnetic attraction process;
- the use of numerous and complex sub-stations that are needed, every 25 km at least, to feed the Maglev guideway with electric current variable in frequency (0-250 Hz) and voltage (0-5 kV).

The total annual cost for Rail in 1991 amounts to $35,61 M/year (in 1983 Canadian dollars). For Maglev, it is $56,42 M/year, a Maglev to Rail annual cost ratio of 1,58. A major cause for this difference is the annual charge for power supply to the numerous and complex wayside substations required for the Maglev system.

A better way to compare the financial performance of these two systems is to evaluate the expected ticket cost. That is, how much revenue would a typical ticket have to bring in to cover all annual costs as well as financial charges associated with capital costs and provisions for asset replacement, thus maintaining the operation profitable and solvent?

A one-way ticket between Montreal and Ottawa would cost (in 1983 Canadian dollars) $68 for Rail and $99 for Maglev. A comparable ticket presently costs $25 by rail and $80 by air. The Maglev/Rail expected ticket cost ratio is thus 1,64: a Maglev ticket would cost 64% more than a Rail ticket. This ratio is lower than that of capital costs, because of Maglev's higher traffic, due to its greater speed. It should also be stressed that, although costing 64% more, the Maglev ticket purchases a 35% travel time improvement vis-à-vis Rail.

Changes in capital and operating costs, however, could alter the conclusions in ticket costs differences between the Maglev and Rail systems. The occurrence of such changes is probable in two specific cases for the Maglev system:

- development of a less complex power and distribution system (already in progress);

- actual experience with system maintenance (due to lack of experience, a conservative approach was used in the study and this may have overestimated maintenance costs for Maglev).

The above conclusions apply to "full-scale" systems using a double track or guideway all the way between Montreal and Ottawa. If these two "basic" systems are scaled down to consist of only those equipments effectively required for the Montreal-Ottawa service, the Maglev/Rail ticket cost ratio is lowered from 1,78 to 1,55, but the 35% improvement in travel time is preserved.

The comparative impact evaluation identified significant differences between the two systems on several aspects only.

The first is the technical maturity of both systems. Whereas railways have been operated for over 100 years, Maglev systems have been in development for less than 20. As a result, there is at present a greater number of risks associated with the decision to implement a Maglev system. Over time, with continued systematic testing and eventual revenue operation, Maglev will progressively bridge that gap.

The second concerns the physical and functional impacts associated with the presence of the right-of-way and the infrastructure, and the resulting flexibility (or lack of it) that a system enjoys if those impacts are to be maintained at an acceptable level.

In dense urban areas, if a new right-of-way must be created, it will probably be underground, in which case Maglev will incurr higher costs. If existing railway rights-of-way are to be used, Rail will be easier to insert in them; existing expressways are not likely to provide suitable lodging for a HSGT guideway in an urban area.

In rural areas, creation of a new right-of-way entails fewer problems. The most economical solution is to insert the HSGT at grade in an existing railway right-of-way or an expressway. In the case of a railway, however, the need to protect the HSGT with fences will disrupt rural activities to a level that could be untolerable. An elevated guideway would then be a logical choice; in that case, the additional cost is much lower for Maglev than for Rail.

This differences discussed above, especially the difference in ticket cost, reflect differences in technology between the two systems, but also, and, perhaps to a much greater degree, the difference in speed between 200 km/h and 400 km/h.

The technologies compared are such that the Maglev system, as designed in this study, can accept increases in capacity much easier and at a lower cost than the Rail system: the guideway being divided into 14 segments, up to 14 Maglev trains could be supplied with the substations that are required for only two trains. By constrast, any increase in the number of Rail trains would require an increase of the Rail power supply equipment.

Also, increases in speed are probably easier to achieve with the Maglev system, as operating and maintenance costs of the Rail system would increase very significantly as the maximum speed is increased.

Finally, if both systems had been designed for 300 km/h, the Maglev/Rail ticket cost ratio would have been very significantly closer to 1,00.

The above conclusions must be interpreted in light of two significant characteristics of the present study.

First, the application envisioned is not the ideal one for the implementation of a HSGT system: the distance is too short (200 km) and the market potential is too low. As a result, capital costs may appear high in relation to traffic, resulting in relatively expensive ticket costs. This tends to cast doubts on the feasibility of implementing a HSGT system in that corridor: this was known before starting the study, which was only indirectly concerned with feasibility. As for the direct purpose of the study, the choice of a short distance tends to bias the comparison in favor of Rail. On a longer distance, the ratio of capital costs would be about the same. With its higher speed and greater travel time savings, Maglev's competitive advantage and its ridership would be enhanced. The Maglev/Rail ticket cost ratio would decrease. A similar comparative assessment should preferably be based on an application with a minimum terminal-to-terminal distance of 300 to 400 km.

Second, the difference in speed is great: one system doubles the maximum speed of the other. These speeds were specified at the outset. The result is that the comparison measures two types of effects: these due to speed and those due to technology alone. Reducing the speed gap would naturally lower all cost ratios, but, primarily, it would only measure the effects on technology. A similar comparative assessment should preferably consider systems with a difference in maximum operating speeds under 100 km/h, ideally under 50 km/h.

Transport Canada
Transportation Development Centre

Technical Appendices

Comparative Technology Assessment Montreal — Mirabel — Ottawa High Speed Ground Transport

TP5457E

Canatrans Consultants Ltd.
with Transrapid International

December 1984

Canatrans Project No. 37229

TP 5457E

COMPARATIVE TECHNOLOGY ASSESSMENT:
MONTREAL - MIRABEL - OTTAWA
HIGH SPEED GROUND TRANSPORT

Final Report

Technical Appendices

Bernard-André Genest, Project Manager
Peter Jurgen Gaede, Marc Girardin, Marc Grégoire, Charles Schwier

This research was conducted under Supply and Services Canada Contract No. OSD82-00061, on behalf of the Advanced Technology Division, Transportation Development Centre, Transport Canada

Canatrans Consultants Ltd., Montreal (Quebec) Canada
with
Transrapid International, München (Federal Republic of Germany)

December 1984

This report resulted from research conducted through Canatrans Consultants Ltd. with Transrapid International. The report represents the views of the authors and does not necessarily have the endorsement of the performing organizations or that of the sponsoring agency.

REPORT DOCUMENTATION FORM

1 Transport Canada Report No
TP 5457E

2 TDC Project No
4609

3 Recipient's Catalogue No

4 Title and Subtitle
Comparative Technology Assessment:
Montreal - Mirabel - Ottawa
High Speed Ground Transport

5 Report Date
December 1984

6 Performing Organization Report No
37229

7 Author(s)
Bernard-André Genest, Peter Jurgen Gaede,
Marc Girardin, Marc Grégoire, Charles Schwier

8 Transport Canada File No
D1465-356-2

9 Performing Organization Name and Address
Canatrans Consultants Ltd.
1130, west, Sherbrooke Street
Montreal, Quebec, Canada H3A 2R5

10 DSS File No
10SD.T8200-2-2503

11 DSS or Transport Canada Contract No
0SD82-00061

12 Sponsoring Agency Name and Address
Transportation Development Centre (TDC)
Transport Canada
1000 west, Sherbrooke Street, suite 2421
Montreal, Quebec, Canada H3A 2R3

13 Type of Report and Period Covered
Final Report

14 Sponsoring Agency Code

15 Supplementary Notes
Report comprises two volumes: 1. Chapters 1 to 9
2. Technical Appendices

16 TDC Project Officer
Maurice Audette

17 Abstract

This report presents a comparative assessment of two technologies for high speed ground transport (HSGT): an electrified rail system using conventional wheel-on-rail technology with a maximum operating speed of 200 km/h, and an advanced system using magnetic attraction for vehicle support, guidance, and propulsion, with a maximum operating speed of 400 km/h.

The comparison is based on a given hypothetical application: service between Montreal and Ottawa, a distance of some 200 km, through Mirabel International Airport. Based on their technical characteristics and performance, a conceptual system design was developed for each technology, against common service specifications formulated to reflect the requirements of that application.

Detailed capital and operating cost estimates are presented. The estimated ticket cost is used as a basis for a comparative financial analysis; the sensitivity of that cost to the relevant economic parameters is explored. The report also contains an evaluation of the differences in impacts between the two technologies with emphasis on the environmental insertion of guideways for HSGT systems.

18 Key Words
High Speed Ground Transport, High Speed Rail, Maglev, Intercity Passenger Transport, Montreal, Ottawa, Financial Analysis, Impact Evaluation, Technology Assessment

19 Distribution Statement
Limited number of copies available from TDC.

20 Security Classification (of this report)
unclassified

21 Security Classification (of this page)
unclassified

22 No of Pages
vol.1 352
vol.2 294

23 Price

TDC CDT 79.005

FORMULE DE DOCUMENTATION POUR RAPPORT

1 Nº du rapport Transports Canada
TP 5457E

2 Nº de l'étude — CDT
4609

3 Nº de catalogue du destinataire

4 Titre et sous-titre
Comparative Technology Assessment:
Montreal - Mirabel - Ottawa
High Speed Ground Transport

5 Date du rapport
Décembre 1984

6 Nº du rapport de l'organisme exécutant
37229

7 Auteur(s)
Bernard-André Genest, Peter Jurgen Gaede,
Marc Girardin, Marc Grégoire, Charles Schwier

8 Nº de dossier Transports Canada
D1465-356-2

9 Nom et adresse de l'organisme exécutant
Canatrans Consultants Ltée
1130 ouest, rue Sherbrooke
Montréal, Québec, Canada H3A 2R5

10 Nº de dossier — ASC
10SD.T8200-2-2503

11 Nº de contrat — ASC ou Transports Canada
0SD82-00061

12 Nom et adresse de l'organisme parrain
Centre de développement des transports (CDT)
Transports Canada
1000, ouest, rue Sherbrooke, suite 2421
Montréal, Québec, Canada H3A 2R3

13 Genre de rapport et période visée
Rapport final

14 Code de l'organisme parrain

15 Remarques additionnelles
Rapport en deux volumes: 1. Chapitres 1 à 9
2. Annexes techniques
Rapport sommaire disponible en français

16 Agent de projet — CDT
Maurice Audette

17 Résumé

Ce rapport présente une évaluation comparative de deux technologies de transport terrestre guidé à grande vitesse: un système ferroviaire électrifié utilisant la technologie fer-sur-fer conventionnelle et doté d'une vitesse d'exploitation maximale de 200 km/h d'une part; et un système à technologie avancée utilisant des principes d'attraction magnétique pour la sustentation, le guidage et la propulsion du véhicule, d'autre part, ce dernier étant capable d'une vitesse d'exploitation maximale de 400 km/h.

La comparaison est basée sur une application hypothétique: un service grande vitesse entre Montréal et Ottawa, une distance de 200 km environ, via l'aéroport international de Mirabel. A partir de leurs données techniques et de performance, on a effectué pour chaque technologie la conception schématique d'un système complet à des normes de service communes, formulées pour répondre aux exigences de la clientèle envisagée.

Des estimations détaillées des coûts de mise en oeuvre et d'exploitation sont présentées dans le rapport, de même qu'une analyse financière comparative basée sur une évaluation du coût du titre de transport pour chaque système. On analyse la sensibilité de ce coût à des variations de la valeur des principaux paramètres économiques pertinents. Le rapport comprend aussi une évaluation des deux technologies quant aux différences dans leurs impacts; on y met l'accent sur les difficultés d'insertion dans le milieu des couloirs de circulation des systèmes de transport terrestre grande vitesse.

18 Mots-clés
Transport terrestre à grande vitesse, Transport Ferroviaire, sustentation magnétique, Transport Interurbain, Montréal, Ottawa, Evaluation d'impacts comparaison technologique.

19 Diffusion
Le CDT dispose d'un nombre limité d'exemplaires.

20 Classification de sécurité (de ce rapport)
aucune

21 Classification de sécurité (de cette page)
aucune

22 Nombre de pages
vol.1 352
vol.2 294

23 Prix

TABLE OF CONTENTS

Page

A. REVIEW OF PREVIOUS STUDIES 1
- A.1 Intercity Passenger Transport Study 2
- A.2 Mode Choice for Intercity Passenger Travel 8
- A.3 Passenger Transportation between Montreal and Ottawa 14
- A.4 STOL and Short Haul Air Transportation in Canada 21
- A.5 Freight and Passenger Forecasts 1981 26
- A.6 Alternatives to Air 29
- A.7 Intercity Passenger Transport Energy Efficiency 38
- References 40

B. TECHNICAL DOCUMENTATION ON MAGLEV 41
- B.1 Vehicle Concept 42
- B.2 Energy Consumption of Magnetic Levitation System 44
- B.3 Long Stator Synchroneous Linear Motor 46
- B.4 Emsland TransRapid Test Facility 48
- B.5 Guideway at the Emsland Test Facility 51
- B.6 Geometric Design of High Speed Guideways 53
- References 54

C. DESCRIPTION OF THE MAGLEV ROUTE 55
- C.1 Montreal Downtown Area 57
- C.2 Dorval Area 60
- C.3 Laval - Mirabel Area 65
- C.4 Mirabel Airport Area 68
- C.5 Lachute Area 70
- C.6 Hawkesbury Area 72
- C.7 Alfred Bog Area 74
- C.8 Plantagenet Area 76
- C.9 Hammond to Navan Area 78
- C.10 Ottawa Area 80
- Reference 82

D. DESCRIPTION OF THE RAIL ROUTE 83
- D.1 Montreal Area 85
- D.2 Laval - Deux-Montagnes Area 88
- D.3 Two Mountain Area 92
- D.4 Mirabel Airport Station 94
- D.5 Mirabel Airport to Saint-Placide 96
- D.6 Ottawa River Crossing 98
- D.7 Vankleek Hill Area 100
- D.8 Alfred Bog Area 102
- D.9 Plantegenet - Bourget Area 104
- D.10 Hammond - Navan Area 106
- D.11 Ottawa Area 108

TABLE OF CONTENTS (Cont'd.)

Page

E. RAIL SYSTEM DOCUMENTATION 111
E.1 Line Capacity 111
E.1.1 Capacity Requirement 111
E.1.2 Load Factor and Capacity Adjustment 112
E.1.3 Trip Time 114
E.2 Vehicle Performance Definition 118
E.2.1 Review of Existing Trains 118
E.2.2 Selection of Car Weight 120
E.2.3 Train Resistance Calculation 120
E.2.4 Tractive Effort Characteristics 122
E.2.5 Braking Performance 130
E.2.6 Performance of the Rail Technology 130
E.2.7 Trip Time Calculation 130
E.2.8 Appraisal of Vehicle Performance Evaluation 132
E.3 Infrastructure 136
E.3.1 Track Layout 136
E.3.2 Right-of-way 151
E.3.3 Soil Conditions along the Route 151
E.3.4 Quantity Estimation for Trackwork 151
E.3.5 Quantity Estimation for Turnouts 153
E.4 Grade Separation Structures 162
E.4.1 Need for and Types of Grade Separation Structures 162
E.4.2 Street-under-Rail Structures 167
E.4.3 Highway-over-Rail Structures 169
E.4.4 Road-over-Rail Structures 172
E.4.5 Special Structures 176
E.4.6 Rail-over-Rail Structures 176
E.4.7 Tunnel at Mirabel 178
E.5 Bridges and Culverts 181
E.6 Stations 190
E.6.1 Space Requirements 190
E.6.2 Central Station 192
E.6.3 West Island Station 192
E.6.4 Mirabel Airport Station 193
E.6.5 Ottawa Terminal 194
E.6.6 Other Station Costs 194
E.7 Power Supply Equipment 197
E.7.1 Location of Feed Points 197
E.7.2 Schematic Design 200
E.7.3 Equipment Sizing 202
E.8 Power Distribution Equipment 205
E.9 Command and Control Equipment 214
E.9.1 Control Center 215
E.9.2 Wayside Equipment - Interlockings 218
E.9.3 Wayside Equipement - Intermediate Areas 220
E.9.4 On-Board Equipment 222
E.9.5 Equipment Requirements 224
E.9.6 Capital Cost Estimates 224

TABLE OF CONTENTS (Cont'd.)

Page

F. MAGLEV SYSTEM DOCUMENTATION 229
F.1 Line Capacity 229
F.1.1 Capacity Requirement 229
F.1.2 Load Factor and Capacity Adjustment 230
F.1.3 Trip Time 232
F.1.4 Schedule and Consist Assignment 237
F.2 Vehicle Description and Performance 239
F.2.1 Structure and Layout 239
F.2.2 Bogies 239
F.2.3 Propulsion 242
F.2.4 Braking 244
F.2.5 Vehicle Performance 244
F.3 Infrastructure 246
F.3.1 Guideway Layout 246
F.3.2 Right-of-Way Requirements 250
F.4 Design and Cost of Guideway Foundation Elements 255
F.4.1 Design Conditions and Parameters 255
F.4.2 Foundations Elements: Guideway at Grade 257
F.4.3 Foundation Elements: Elevated Guideway 258
F.4.4 Footings for Elevated Guideways on Good Soil 260
F.4.5 Pile Caps for Elevated Guideways on Poor Soil 262
F.4.6 Rigid Frames for Elevated Guideways over Railways 264
F.5 Guideway Configuration Design 267
F.6 Costs of River Crossings 270
F.7 Stations 275
F.7.1 Space Requirements 275
F.7.2 Montreal Terminal 276
F.7.3 West Island Station 278
F.7.4 Mirabel Airport Station 279
F.7.5 Ottawa Terminal 280
F.7.6 Other Station Costs 282

LIST OF FIGURES

Page

A-1 Montreal Origins of Montreal - Ottawa Travelers 3
A-2 Montreal Destinations of Montreal - Ottawa Travelers 4
A-3 Ottawa Origins of Montreal - Ottawa Travelers 5
A-4 Ottawa Destinations of Montreal - Ottawa Travelers 6
A-5 Source of STOL Passengers and Modal Shares 24

B-1 Maglev Test Track in Emsland 49

C-1 Key Map for Maglev Route 56
C-2 Montreal Dowtown Area 59
C-3 Dorval Area 61
C-3a Maglev Routing around Dorval Airport 62
C-4 Laval - Mirabel Area 67
C-5 Mirabel Airport Area 69
C-5a Maglev Routing around Mirabel Airport 68
C-6 Lachute Area 71
C-7 Hawkesbury Area 73
C-8 Alfred Bog Area 75
C-9 Plantagenet Area 77
C-10 Hammond - Navan Area 79
C-11 Ottawa Area 81

D-1 Key Map for Rail Route 84
D-2 Montreal Area 87
D-3 Laval - Deux-Montagnes Area 89
D-4 Two Mountain Area 93
D-4a Deux-Montagnes Area 97
D-5 Mirabel Airport Station 95
D-6 Ottawa River Crossing 99
D-7 Vankleek Hill Area 101
D-8 Alfred Bog Area 103
D-9 Plantagenet - Bourget Area 105
D-10 Hammond - Navan Area 107
D-11 Ottawa Area 109

E-1 Tractive Effort and Resistance as a Function of Speed 126
E-2 Acceleration as a Function of Speed 127
E-3 Speed and Distance as a Function of Time: Acceleration 128
E-4 Power, Efficiency, and Power Factor as a Function of Speed 129
E-5 Speed and Distance as a Function of Time: Normal Service Braking 133
E-6 Speed and Distance as a Function of Time: Acceleration & Braking 134
E-7 Speed as a Function of Distance over the Rail Route 135
E-8 Track Layout for the Rail Route (11 pages) 140
E-9 Typical Highway-over-Rail Structure for two Tracks 171
E-10 Typical Highway-over-Rail Structure for three Tracks 173
E-11 Clearances for the Tunnel at Mirabel 177
E-12 Structural Dimensions for the Tunnel at Mirabel 179

LIST OF FIGURES (Cont'd.)

		Page
E-13	Deck Cross-Section for a Three-Track 10 m Bridge	182
E-14	Deck Cross-Section for a Three-Track 40 m Bridge	184
E-15	Concept of a Steel Truss for a 100 m Rail Bridge	186
E-16	Location of Sub-Stations	201
E-17	Schematic Single Line Diagram of Power Supply and Catenary	203
E-18	Catenary Switching Arrangement	204
E-19	Major Catenary Types for a 25 kV System	207
E-20	Conductor Sections for Rail Catenary	208
E-21	Automatic Tension Regulation System	209
E-22	Typical Catenary Suspension in Tunnel	210
E-23	Structures for Catenary Suspension over multiple tracks	211
E-24	Catenary Support Systems for two Tracks	212
E-25	Typical Catenary Support Foundations	213
E-26	Symbols Used on Signal Plans for Rail	217
E-27	Wayside Equipment at Typical Interlockings	219
E-28	Wayside Equipment at Special Interlockings	221
F-1	Maglev Simulated Speed Profile Between Montreal and Ottawa	233
F-2	Cross-Section of the Maglev Vehicle	240
F-3	Car-Body Structure Design	241
F-4	Cross-Section of the Maglev Bogie	243
F-5	Acceleration and Deceleration for a Maglev Vehicle	245
F-6	Summary Guideway Schematic for Maglev	247
F-7	Clearance for an Elevated Guideway	251
F-8	Right-of-Way Requirements for a Guideway at Grade	253
F-9	Footing for a Straight Guideway with a 5 m clearance	259
F-10	Footing for a Curved Guideway with a 5 m clearance	261
F-11	Cost Behaviour of Guideway Foundation Elements	263
F-12	Concept of a Guideway Structure over 2 Tracks	265
F-13	Concept of a Guideway Structure over 3 Tracks	266

LIST OF TABLES

		Page
A-1	Travel Demand and Forecasts	7
A-2	1972 Estimated Modal Split for Montreal-Ottawa	11
A-3	Components of Modal Split Forecasts	12
A-4	Modal Split Forecasts for Montreal-Ottawa	13
A-5	Estimated Passenger Market by Modes, Montreal-Ottawa	15
A-6	Estimated Modal Split, Montreal-Ottawa	16
A-7	Estimated Passenger Volumes by Mode, (Work days only)	17
A-8	Modal Split for Work Days, 1973-76	18
A-9	Montreal-Ottawa Traffic, 1974, 1975	19
A-10	Montreal-Ottawa Traffic, 1974, 1975, Work Days Only	20
A-11	Projected Annual One Way Traffic Forecasts, by Mode	25
A-12	Overall Expected Growth Rate by Mode (Canada)	27
A-13	Expected Annual Growth Rate by Mode (Quebec and Ontario)	28
A-14	Total Travel Demand Forecasts for Montreal-Ottawa	31
A-15	Unfactored Travel Demand by City Pair	32
A-16	Gross Travel Demand by City Pair	33
A-17	1977 City Pair Modal Splits	34
A-18	Modal Splits, Status Quo Scenario	35
A-19	Modal Splits, Optimistic Scenario	36
A-20	Modal Splits, Pessimistic Scenario	37
A-21	Toronto - Ottawa - Montreal Transport System - 1976	39
E-1	Rail Capacity Requirements and Load Factors	113
E-2	Rail Schedule and Consist Assignment	115
E-3	Rail Route Characteristics	116
E-4	Trip Time between Montreal, Mirabel, and Ottawa	117
E-5	Acceleration Performance of Selected Trains	119
E-6	Service Braking Rates for Conventional Equipment	121
E-7	Calculated Values of Resistance as a Function of Speed	123
E-8	Parameter Definition for Acceleration Calculations	124
E-9	Acceleration Characteristics of the Rail Technology	125
E-10	Deceleration Characteristics of the Rail Technology	131
E-11	Number of Tracks in the Right-of-Way	154
E-12	Right-of-Way Acquisition Requirements by Location	156
E-13	Soil Qualification as a Function of Soil Type	155
E-14	Soil Quality along the Rail Route	158
E-15	Quantity Estimation for Trackwork	160
E-16	Location, Type, and Arrangement of Turnouts	161
E-17	Location of Grade Separation Structures	163
E-18	Characteristics of Street-under-Rail Structures	168
E-19	Characteristics of Highway-over-Rail Structures	170
E-20	Characteristics of Road-over-Rail Structures	174
E-21	Bridges on the Rail Route	187
E-22	Culverts on the Rail Route	188
E-23	Estimated Passenger Handling Capacity at Rail Stations	191
E-24	Construction Costs for Rail Stations	195

LIST OF TABLES (Cont'd.)

		Page
E-25	Basic Data for Power Supply Equipment Dimensioning	198
E-26	Sample Calculation for Power Supply Dimensioning	199
E-27	AAR Counts for Typical Interlocking	225
E-28	AAR Counts for Special Interlocking	227
E-29	Cost Breakdown for Signalling Sub-System	228
F-1	Traffic Forecasts, Capacity, and Load Factor for Maglev	231
F-2	Maglev Route Characteristics	234
F-3	Trip Time between Montreal, Mirabel, and Ottawa by Maglev	236
F-4	Trip and Train Consist Schedule for Maglev	238
F-5	Access Road Requirements along the Maglev Route	254
F-6	Guideway Foundation Elements by Type	268
F-7	Cost Surplus for River Crossings	271
F-8	Unit Kilometric Costs for Guideway Construction	272
F-9	Structural Requirements of River Crossings	273
F-10	Construction Cost Indices for Various Guideway Structures	274
F-11	Estimated Passenger Handling Capacity (Maglev)	275
F-12	Maglev Station Construction Costs	281

A. REVIEW OF PREVIOUS STUDIES

This appendix presents the key findings of a review of litterature on travel demand and modal split in between Montreal and Ottawa.

As such, Appendix A complements Chapter 1. The appendix has been subdivided in six sections, each corresponding to a different report.

A.1 Intercity Passenger Transport Study

This study was done in house by the Research Branch of the Canadian Transport Commission and was published in September 1970.

The study(1)* was undertaken to "provide a preliminary evaluation of the potential application of new technology to intercity passenger travel in Canada", with special emphasis on the Montreal - Ottawa - Toronto Corridor.

This study provides estimates and forecasts of travel demand for public transportation services from 1969 to 1990 (Table A-1). The study, however, did not consider the automobile mode.

According to the study, the 1969 modal split on the Montreal - Ottawa route was approximately:

Air	:	7%
Rail	:	57%
Bus	:	36%

It also gives modal split estimates for different rail strategies:

Strategy	Modal Share Air	 Rail (travel time)	 Bus
Present technology	10%	57% (1h59)	33%
High speed rail	10%	59% (1h40)	31%
Tracked Air Cushion Vehicle	2%	85% (1h05)	13%

---

* Numbers in parentheses correspond to entry numbers in the list of references at the end of each appendix

Source: "Mode Choice for Intercity Passenger Travel Montreal-Ottawa", by Transport Canada in August 1976.

Zone	Bus	Air	Train	Car
1	4%	0%	1%	2%
2	2%	1%	1%	2%
3	4%	1%	2%	2%
4	4%	1%	2%	1%
5	3%	1%	2%	2%
6	3%	1%	1%	2%
7	24%	25%	24%	10%
8	1%	1%	1%	1%
9	10%	9%	16%	7%
10	3%	1%	2%	1%
11	3%	1%	1%	2%
12	8%	8%	8%	9%
13	3%	3%	4%	5%
14	9%	7%	11%	8%
15	3%	7%	4%	7%
16	1%	10%	1%	6%
17	2%	5%	2%	8%
18	0%	10%	2%	12%
19	1%	1%	1%	1%
20	3%	1%	4%	5%
21	6%	3%	7%	4%
22	3%	3%	3%	3%
Total	100%	100%	100%	100%

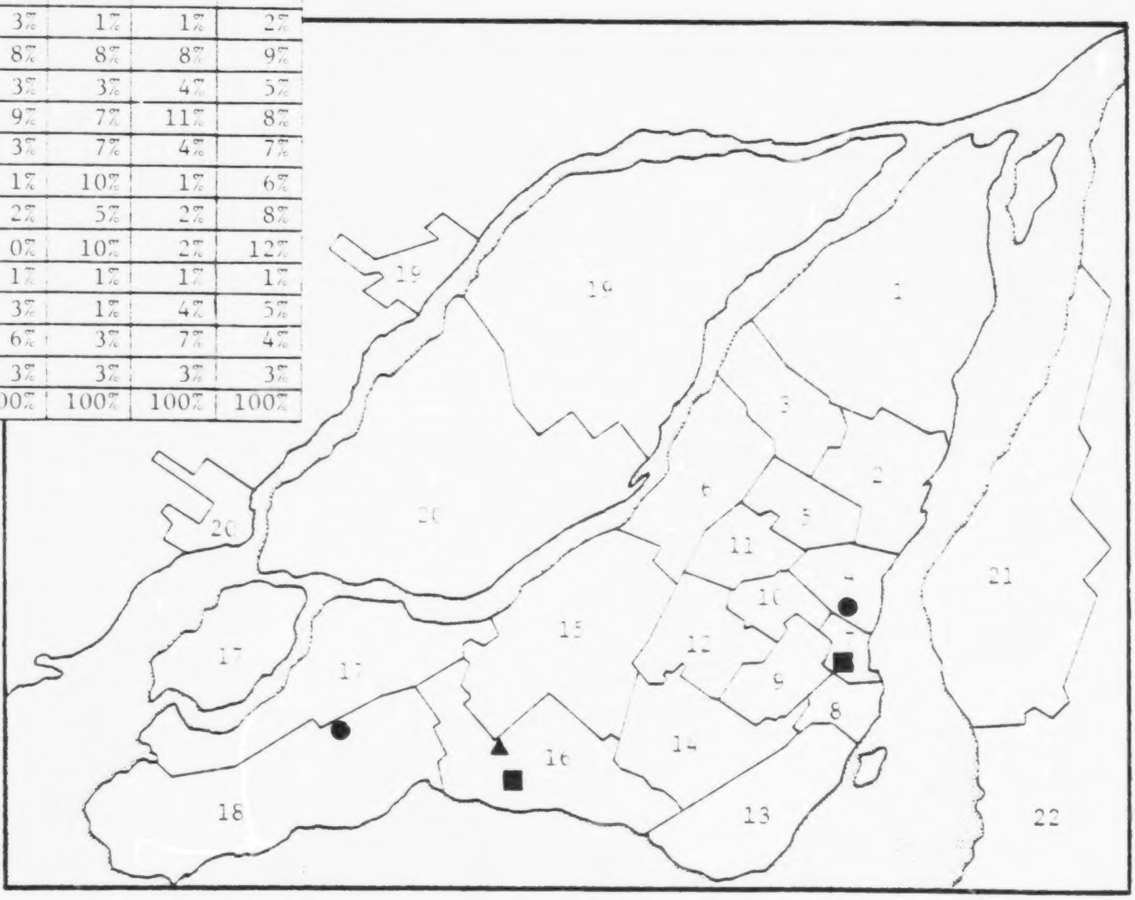
Legend:

Intercity Passenger Terminals:

▲ Air

■ Rail

● Bus



Note: This is based on a 1972 survey, at that time the Voyageur Terminal was at Fairview Shopping Centre.

Figure A-1 Montreal Origins of Montreal-Ottawa Travelers

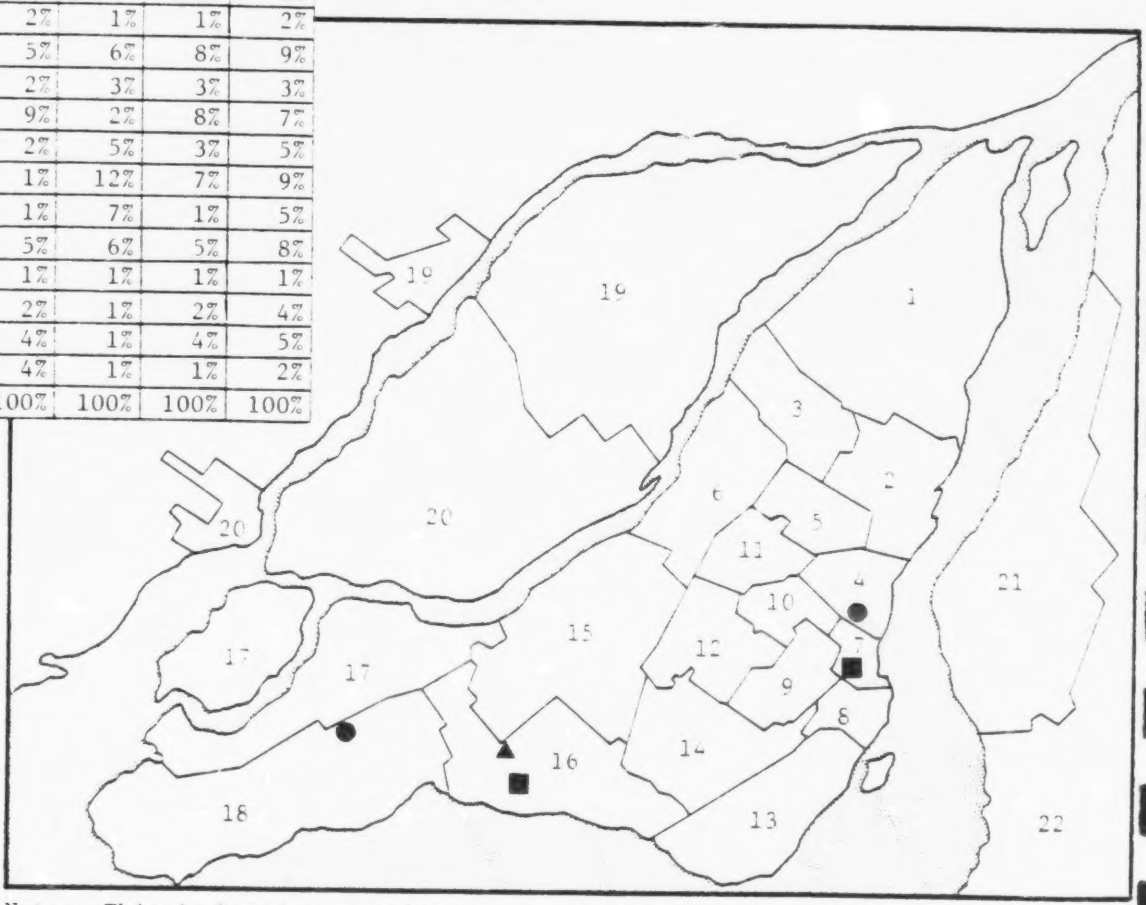
Source: "Mode Choice for Intercity Passenger Travel Montreal-Ottawa", by Transport Canada in August 1976.

Zone	Bus	Air	Train	Car
1	1%	3%	1%	2%
2	4%	1%	1%	1%
3	1%	2%	1%	2%
4	4%	1%	2%	2%
5	1%	1%	1%	2%
6	4%	1%	2%	2%
7	30%	34%	32%	17%
8	1%	1%	1%	1%
9	16%	8%	14%	9%
10	1%	2%	1%	2%
11	2%	1%	1%	2%
12	5%	6%	8%	9%
13	2%	3%	3%	3%
14	9%	2%	8%	7%
15	2%	5%	3%	5%
16	1%	12%	7%	9%
17	1%	7%	1%	5%
18	5%	6%	5%	8%
19	1%	1%	1%	1%
20	2%	1%	2%	4%
21	4%	1%	4%	5%
22	4%	1%	1%	2%
Total	100%	100%	100%	100%

Legend:

Intercity Passenger Terminals:

▲ Air
■ Rail
● Bus



Note: This is based on a 1972 survey, at that time the Voyageur Terminal was at Fairview Shopping Centre.

Figure A-2 Montreal Destinations of Montreal-Ottawa Travelers

Zone	Bus	Air	Train	Car
1	0%	0%	1%	1%
2	10%	2%	8%	10%
3	1%	1%	3%	2%
4	8%	9%	12%	12%
5	1%	3%	1%	2%
6	2%	5%	1%	2%
7	6%	7%	12%	8%
8	34%	29%	28%	23%
9	16%	3%	9%	7%
10	11%	15%	9%	12%
11	9%	15%	12%	13%
12	2%	11%	4%	6%
Total	100%	100%	100%	100%

Source: "Mode Choice for Intercity Passenger Travel Montreal-Ottawa", by Transport Canada in August 1976.

Legend:

Intercity Passenger Terminals:

- ▲ Air
- ■ Rail
- ● Bus

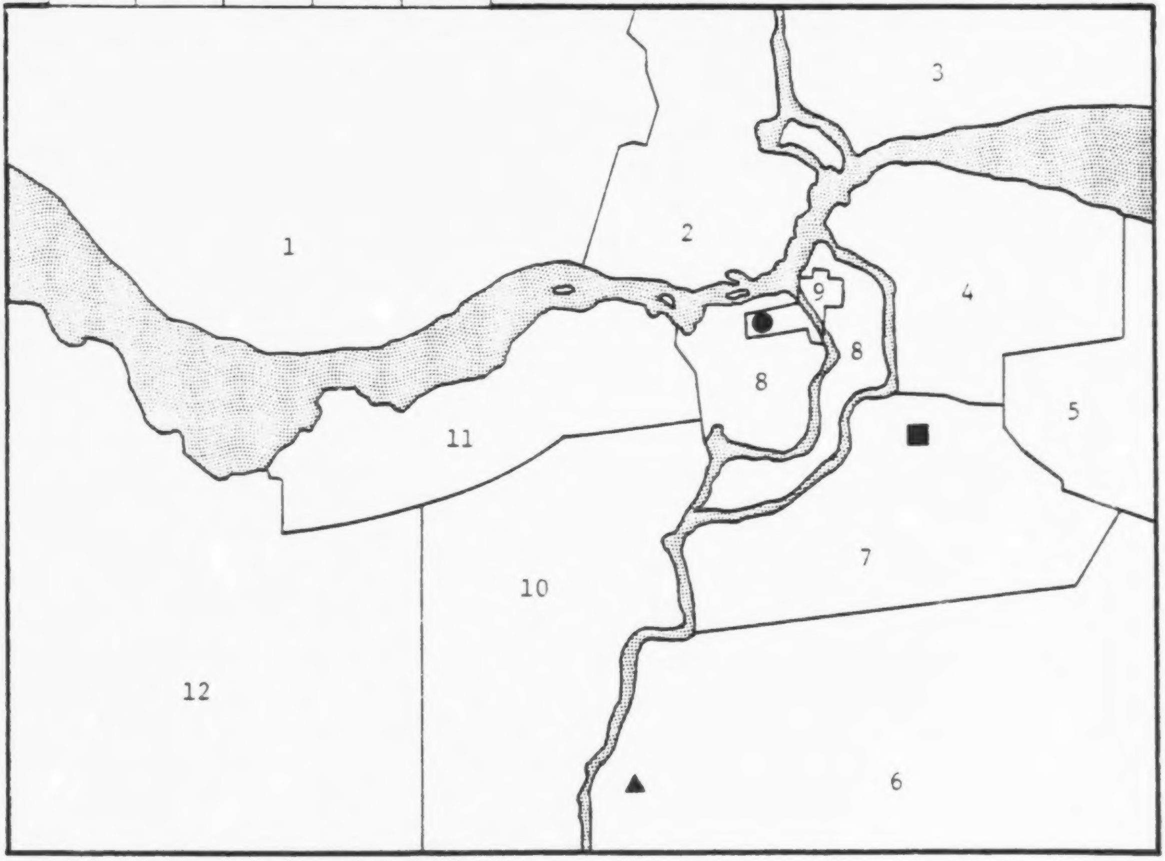


Figure A-3 Ottawa Origins of Ottawa-Montreal Travelers

Zone	Bus	Air	Train	Car
1	1%	1%	0%	1%
2	7%	4%	2%	9%
3	2%	2%	2%	3%
4	9%	7%	8%	10%
5	1%	1%	3%	3%
6	1%	2%	2%	2%
7	3%	9%	9%	7%
8	41%	41%	45%	29%
9	14%	6%	14%	15%
10	9%	15%	5%	8%
11	11%	7%	6%	10%
12	1%	5%	4%	3%
Total	100%	100%	100%	100%

Source: "Mode Choice for Intercity Passenger Travel Montreal-Ottawa", by Transport Canada in August 1976.

Legend:

Intercity Passenger Terminals:

- ▲ Air
- ■ Rail
- ● Bus

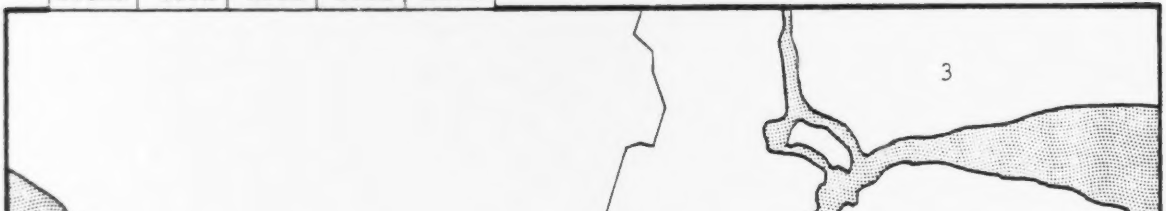


Figure A-4 Ottawa Destinations of Ottawa-Montreal Travelers

Table A-1

Travel Demand and Forecasts

Year	Air	Rail	Bus	Total
1969	49	402	254	705
1970	51	416	263	730
1975	77	624	394	1 095
1980	103	832	525	1 460
1985	136	1 104	697	1 937
1990	175	1 425	900	2 500

Source: Intercity Passenger Transport Study (1).
Note : These figures were scaled off the graphs contained in the report.

A.2 Mode Choice for Intercity Passenger Travel

The report of that study, entitled "Mode Choice for Intercity Passenger Travel Montreal - Ottawa, A working paper" was published by Transportation Development Agency as TP234 in August 1976.

This report (2) presents the results of the Intercity Passenger Travel Forecasting Project initiated in 1971. Results of surveys conducted in 1972 are given and these of a modal split analysis based on an n-dimensional logit modal are also given.

An estimation of the 1972 modal split is presented in Table A-2. Forecasts were also developped for different improvements of transportation services. These are given in Tables A-3 and A-4.

The report presents the most significant results of traveler surveys conducted as part of the study. The survey questionnaire sollicited answers from the travelers on the following parameters of their trip: purpose; group size distribution; precise origin and destination; mode, time, and cost of access to the terminal in the origin city and egress from the terminal in the destination city; car availability; travel time and cost by car; subjective importance of the various attributes of the different modes (the mode used and the others) and the travelers' preference ratings in this respect. A thorough statistical analysis (including discriminant and factor analysts) was performed on the attitudinal data thus gathered.

In addition to major conclusions of that study, the data presented on the following parameters is considered most relevant for the present study: trip purpose, mainly to differentiate between business and pleasure; local origin and destination, to assist in locating terminals and intermediate stations if any; attribute preference rating, to ensure that the HSGT is designed to respond to preferences effectively formulated by Montreal - Ottawa travelers. Several of that study's most important findings are quoted below.

"The majority of Montreal - Ottawa travelers come from and go to the central-west end part of the Montreal Island or the central part of Ottawa. As the majority of all travelers leave from or return to their residences, accessibility to terminals from urban areas is of great importance." (2, p.83).

Local origins and destinations in Montreal and Ottawa, as known from the survey, were shown in Figures A-1 through A-4.

The survey also revealed the following distribution between business and pleasure trip purposes: bus passengers: 25 to 38% business; air passengers: 80 to 100% business; rail passengers: 41 to 53% business; automobile drivers and passengers: 31 to 41% business. The range in values results from the fact that travelers were sampled in March and in August. If one adopts the mid-points of the above ranges together with today's estimated modal split (Table 1-4), this corresponds to an overall split between business and pleasure as follows: 37% business, 63% pleasure.

"For business trips, over 95% of all rail and air travelers and about 80% of all car and bus travelers reported all expenses paid for the trip" (2, p.83).

This implies that business travelers will not be very sensitive to price in their choice of mode.

"In response to a question asking them to list the three most important attributes used in their selection of the mode of transport for the trip, travelers of all modes, both business and pleasure, listed "convenience of schedule", "door-to-door travel time", and "safety" most prominently. Business travelers on air and rail also listed "being confident of arriving on time"; on bus, "minimum of advance arrangements" was listed; and on car "convenience of auto at destination" was listed as frequently as the above three attributes" (p.84). Pleasure travelers on bus, train, and car listed "total costs" as frequently as the three basic attributes; when on air, they also listed " being confident of arriving on time".

"Mean overall ratings of the modes for Montreal - Ottawa trips by business travelers were consistently in the order: 1- car, 2- rail, 3- air, 4- bus, with the mode in use in first position. Pleasure travelers rated the modes nearly equally ..." (p.84).

"There are two basic factors underlying the responses to the importance questions and the modal ratings, ..., a "comfort" dimension and a "time and schedule" dimension... In determining modal preferences, "car at destination" was again the overriding variable in the importance ratings section." (p.85).

"In designing a new mode or upgrading an existing mode, priority should be given to the following in the hope of maximizing passenger demand:

a) making the mode comfortable, keeping the noise level down, making the seats comfortable, having an overall pleasant design to the mode's interior and working on methods to minimize passenger fatigue;

b) having a car readily accessible at the passengers' destination;

c) reducing overall travel time by all possible methods, e.g. increasing speed, reducing waiting time, and improving schedule to optimize passenger convenience;

d) reducing costs as much as possible" (2, p.85).

Table A-2

1972 Estimated Modal Split
for Montreal - Ottawa

Mode	Purpose of trifs		
	Business	Pleasure	Combined
Bus	0,085	0,165	0,135
Air	0,093	0,013	0,042
Rail	0,113	0,067	0,084
Car	0,709	0,755	0,739

Source: Mode choice for Intercity Passenger Travel (2).

Table A-3

Components of Modal Split Forecasts

Hypotheses[2]			Mode				
			Bus	Air	Rail	Car	STOL
Present situation			0,135	0,042	0,084	0,739	0,000
STOL Service added:	STOL PT[3] =	STOL PC					
	air	air	0,131	0,037	0,080	0,718	0,032
	air	bus	0,129	0,038	0,079	0,708	0,046
	air $9 fare	bus	0,094	0,035	0,066	0,611	0,195
	car	bus	0,125	0,037	0,076	0,670	0,082
	rail + 2 degrees	air	0,131	0,037	0,077	0,700	0,066
	rail + 2 degrees	bus	0,125	0,037	0,074	0,683	0,080
Rail improvements:	rail PC = bus		0,122	0,042	0,129	0,707	0
	rail PC = bus and rail PT increased 1 degree		0,116	0,039	0,163	0,682	0
Highway 417 added:	bus PT and car PT increased 1 degree		0,149	0,036	0,071	0,744	0
STOL service plus rail improvement STOL PT = car; STOL = bus; rail PC = bus			0,113	0,037	0,115	0,659	0,077
STOL service plus highway 417 STOL PT = car; STOL PC = bus; bus PT and car PT then increased 1 degree			0,138	0,032	0,065	0,697	0,062

Notes:
1. The model results are combined on a basis of 37,5% business trips and 62,5% pleasure trips.
2. Conditions on the present modes are assumed unchanged, except as noted. The STOL fare is assumed to be $15, except as noted. The STOLports are assumed to be at Victoria Parking Lot and Rockliffe Airport.
3. PT is perceived total travel time for a mode. PC is perceived convenience of schedule for a mode.
4. Source: Reference 2.

Table A-4

Modal Split Forecasts for Montreal - Ottawa

Hypothese	Mode				
	Car	Bus	Rail	Air	STOL
Present situation	0,74	0,14	0,08	0,04	--
Rail as convenient as Bus Plus one degree (probably equivalent to hourly rail service, taking 90 minutes)	0,68	0,12	0,16	0,04	--
Bus and Car convenience increased one degree to reflect completion of highway 417	0,74	0,15	0,07	0,04	--
STOL service every hour, 75 minutes downtown-downtown	0,68	0,13	0,07	0,04	0,08

Source: Mode choice for Intercity Passenger Travel (2).

A.3 Passenger Transportation between Montreal and Ottawa

Passenger Transportation between Montreal and Ottawa, 1973-76: An analysis of the impact of the Airtransit STOL Demonstration Service on the passenger volumes of other modes, including the private automobile" was published by Transport Canada, in 1977.

This report (3) is an analysis of passenger travel between Montreal and Ottawa during a period where the STOL Service was in demonstration. During the period analyzed, other events took place and affected the results of the surveys:

- rail strike in July, August and September 1973;
- opening of Highway 417 (first quarter of 1975);
- Olympic games.

Surveys were made for automobile, and counts were obtained for rail, bus and air modes.

From these data, OD passenger volume were estimated. It should be noted that for the air modes, Ottawa - Mirabel passengers were excluded. Results are shown in the Tables A-5 through A-10.

Table A-5

Estimated Passenger Market by Mode
Montreal - Ottawa

		Auto	Bus	Rail	CTOL	STOL	All Modes
1973	Q1	338,400	121,370	60,920	23,300	-	543,990
	Q2	593,250	127,730	52,490	23,120	-	796,590
	Q3	756,020	166,650	23,790	25,580	-	972,040
	Q4	373,030	132,300	51,370	25,780	-	582,480
	Σ	2,060,700	548,050	188,570	97,780	-	2,895,100
1974	Q1	339,980	131,080	60,560	28,470	-	560,090
	Q2	612,480	139,270	47,240	23,070	-	822,060
	Q3	763,380	156,850	41,930	18,960	15,670	996,790
	Q4	402,480	138,130	43,660	17,280	22,190	623,740
	Σ	2,118,320	565,330	193,390	87,780	37,860	3,002,680
1975	Q1	421,120	140,830	40,300	18,270	20,100	640,620
	Q2	659,190	137,940	43,210	15,360	29,560	835,260
	Q3	802,510	160,630	39,220	12,950	22,200	1,037,510
	Q4	427,500	148,790	40,600	13,600	21,760	652,250
	Σ	2,310,320	588,190	163,330	60,180	93,620	3,215,640
1976	Q1	368,950	148,800	44,810	13,650	17,660	593,870
	Q2	660,780	161,730	44,800	12,980	5,320	885,610
	Q3	835,390	202,760	40,050	15,590	-	1,093,790
	Q4	430,670	159,420	42,510	17,780	-	650,380
	Σ	2,295,790	672,710	172,170	60,000	22,980	3,223,650

Note: This is origin - destination traffic only.

Source: Reference 3.

Table A-6

Estimated Modal Split
Montréal - Ottawa

		Auto	Bus	Rail	CTOL	STOL	All Modes
1973	Q1	62.2	22.3	11.2	4.3	-	100.0%
	Q2	74.5	16.0	6.6	2.9	-	100.0%
	Q3	77.8	17.1	2.5	2.6	-	100.0%
	Q4	64.1	22.7	8.8	4.4	-	100.0%
Annual		71.2	18.9	6.5	3.4	-	100.0%
1974	Q1	60.7	23.4	10.8	5.1	-	100.0%
	Q2	74.5	17.0	5.7	2.8	-	100.0%
	Q3	76.6	15.7	4.2	1.9	1.6	100.0%
	Q4	64.5	22.1	7.0	2.8	3.6	100.0%
Annual		70.6	18.8	6.4	2.9	1.3	100.0%
1975	Q1	65.7	22.0	6.3	2.9	3.1	100.0%
	Q2	74.5	15.6	4.9	1.7	3.3	100.0%
	Q3	77.3	15.5	3.8	1.3	2.1	100.0%
	Q4	65.6	22.8	6.2	2.1	3.3	100.0%
Annual		71.8	18.3	5.1	1.9	2.9	100.0%
1976	Q1	62.1	25.1	7.5	2.3	3.0	100.0%
	Q2	74.6	18.3	5.0	1.5	0.6	100.0%
	Q3	76.4	18.5	3.7	1.4	-	100.0%
	Q4	66.2	24.5	6.6	2.7	-	100.0%
Annual		71.2	20.9	5.3	1.9	0.7	100.0%

Note: This applies only to origin-destination traffic only.

Source: Reference 3.

Table A-7

Estimated Passenger Volumes by Mode
Montreal - Ottawa
(Work Days Only)

		Auto	Bus	Rail	CTOL	STOL	All Modes
1973	Q1	190,460	73,000	42,740	17,140	-	323,340
	Q2	282,180	73,880	37,750	15,590	-	409,400
	Q3	402,130	103,730	16,930	17,540	-	540,330
	Q4	194,580	76,890	33,250	18,870	-	323,590
	Σ	1,069,350	327,500	130,670	69,140	-	1,596,660
1974	Q1	192,960	77,120	41,710	20,610	-	332,400
	Q2	294,250	83,280	34,790	15,540	-	427,860
	Q3	413,800	103,340	31,080	13,140	14,390	575,750
	Q4	207,310	86,110	31,120	12,590	20,430	357,560
	Σ	1,108,320	349,850	138,700	61,880	34,820	1,693,570
1975	Q1	205,280	89,320	27,900	13,360	18,500	354,360
	Q2	325,500	85,670	32,330	10,410	26,770	480,680
	Q3	433,540	105,390	29,440	9,070	20,920	598,360
	Q4	220,480	92,880	29,140	9,900	20,530	372,930
	Σ	1,184,800	373,260	118,810	42,740	86,720	1,806,330
1976	Q1	204,080	95,210	30,870	9,970	17,660	357,790
	Q2	311,070	97,390	32,450	8,630	4,970	454,510
	Q3	448,810	129,880	29,610	10,710	-	619,010
	Q4	231,820	101,300	30,870	13,250	-	377,240
	Σ	1,195,780	423,780	123,800	42,560	22,630	1,808,550

Note: This includes only Montreal - Ottawa origin-destination traffic.

Source: Reference 3.

Table A-8

Modal Split for Work Days
Montreal - Ottawa
1973 - 76

		Auto	Bus	Rail	CTOL	STOL	All Modes
1973	Q1	58.9	22.6	13.2	5.3	-	100.0%
	Q2	68.9	18.0	9.3	3.8	-	100.0%
	Q3	74.1	19.2	3.1	3.3	-	100.0%
	Q4	60.2	23.8	10.3	5.7	-	100.0%
Annual		67.0	20.5	8.2	4.3	-	100.0%
1974	Q1	58.1	23.2	12.5	6.2	-	100.0%
	Q2	68.8	19.5	8.1	3.6	-	100.0%
	Q3	71.9	17.9	5.4	2.3	2.5	100.0%
	Q4	58.0	24.1	8.7	3.5	5.7	100.0%
Annual		65.4	20.7	8.2	3.6	2.1	100.0%
1975	Q1	57.9	25.2	7.9	3.8	5.2	100.0%
	Q2	67.7	17.8	6.7	2.2	5.6	100.0%
	Q3	72.4	17.7	4.9	1.5	3.5	100.0%
	Q4	59.1	24.9	7.8	2.7	5.5	100.0%
Annual		65.6	20.7	6.6	2.3	4.8	100.0%
1976	Q1	57.1	26.6	8.6	2.8	4.9	100.0%
	Q2	68.4	21.4	7.1	2.0	1.1	100.0%
	Q3	72.5	21.0	4.8	1.7	-	100.0%
	Q4	61.4	26.9	8.2	3.5	-	100.0%
Annual		66.1	23.4	6.8	2.4	1.3	100.0%

Sources: Table A-7, Reference 3.

Table A-9

Montreal - Ottawa Traffic, 1974, 1975

	Mode	O-D Px One-way trips	Origin of STOL Px	Estimated Px Without STOL	STOL Penetration
1	STOL	38,000 (1.3%)	-	0	-
9	CTOL	87,500 (2.9%)	13,500 (36%)	101,000 (3.4%)	13.4%
7	Rail	193,500 (6.4%)	8,500 (22%)	202,000 (6.7%)	4.2%
	Bus	565,500 (18.8%)	4,000 (10%)	569,500 (19.0%)	0.7%
4	Auto	2,118,000 (70.6%)	10,500 (28%)	2,128,500 (70.9%)	0.5%
	TOTAL	3,002,500 (100%)	36,500 (96%)	3,001,000 (100%)	-
1	STOL	93,500 (2.9%)	-	0	-
9	CTOL	60,000 (1.9%)	33,500 (36%)	93,500 (2.9%)	35.8%
	Rail	163,500 (5.1%)	20,500 (22%)	184,000 (5.7%)	11.1%
7	Bus	588,000 (18.3%)	9,500 (10%)	597,500 (18.6%)	1.6%
5	Auto	2,310,500 (71.8%)	26,000 (28%)	2,336,500 (72.8%)	1.1%
	TOTAL	3,215,500 (100%)	89,500 (96%)	3,211,500 (100%)	-

Source: Reference 3.

Table A-10

Montreal - Ottawa Traffic, 1974, 1975

Work Days Only

	Mode	O-D Px One-way trips	Origin of STOL Px	Estimated Px Without STOL	STOL Penetration
1974	STOL	35,000 (2.1%)	-	0	-
	CTOL	62,000 (3.6%)	12,500 (36%)	74,500 (4.4%)	16.8%
	Rail	138,500 (8.2%)	7,500 (22%)	146,000 (8.6%)	5.1%
	Bus	350,000 (20.7%)	3,500 (10%)	353,500 (20.9%)	1.0%
	Auto	1,108,500 (65.4%)	10,000 (28%)	1,118,500 (66.1%)	0.9%
	TOTAL	1,693,500 (100%)	33,500 (96%)	1,692,500 (100%)	-
1975	STOL	86,500 (4.8%)	-	0	-
	CTOL	42,500 (2.3%)	31,000 (36%)	73,500 (4.1%)	42.2%
	Rail	119,000 (6.6%)	19,000 (22%)	138,000 (7.6%)	13.8%
	Bus	373,500 (20.7%)	8,500 (10%)	382,000 (21.2%)	2.2%
	Auto	1,185,000 (65.6%)	24,500 (28%)	1,209,500 (67.1%)	2.0%
	TOTAL	1,806,500 (100%)	83,000 (96%)	1,803,000 (100%)	-

Source: Reference 3.

A.4 STOL and Short Haul Air Transportation in Canada

This report (4) describes the potential role of the STOL concept in Canada. It is of some interest for the present study as it gives the market share that STOL has been able to capture in demonstration service between Montreal and Ottawa. During the 21 months of the demonstration project,

> "Airtransit travellers were drawn from all of the four existing modes: automobile, bus, train and conventional air service. The two endpoints of the route, Montreal and Ottawa Hull, generated a total of 2,87 million one-way trips between them in 1975. The STOL service captured 3,3% of this market. The greatest impact was felt by conventional air service (CTOL), which lost 37% of its local traffic and accounted for 36% of the STOL passengers. Rail and bus respectively lost 11% and 2% of their local passengers to STOL" (Figure A-5).

The report also contains an analysis of the feasability of STOL for the Quebec - Windsor Corridor. According to the report,

> "Improved rail service in the Corridor would likely take the form of speed-related improvements to existing rail infrastructure and the greater use of Turbo or LRC (light, rapid and comfortable) trains. It would be technically feasible to construct new high-speed rail lines on dedicated tracks that would permit use of equipment capable of maximum speeds of up to 250 kilometres per hour, but the capital cost alone would be extremely high. In view of the heavy infrastructure and equipment costs required for such a high-speed rail system, and the limited potential traffic volumes (compared with those transported by high-speed, intercity passenger rail systems in Japan, England and France), it seems unlikely that this type of high-speed intercity passenger rail service will be established in the Quebec-Windsor corridor in the foreseeable future.
>
> With the exception of the Montreal - Toronto route, substantial improvements in passenger rail services could be made on most corridor routes for relatively small expenditures. The existing

> Montreal - Toronto service now has relatively good frequency (seven trains daily each way) and fast trip times (four hours, ten minutes, for the twice daily Turbos). Improvements on this route would be extremely costly and less cost-effective than improvements on the other corridor route segments.
>
> On the basis of door-to-door travel time estimates for improved rail, CTOL and STOL, it has been concluded that STOL and improved rail would compete for the business travel market on the Montreal - Ottawa and Toronto - London routes. Limited competition might exist between STOL and improved rail on the Montreal - Quebec and Toronto - Windsor routes, but in both cases door-to-door travel time (one-way) would be at least one and one-half hours less with STOL than with improved rail. Considering also the relatively small differences in estimated door-to-door travel time between STOL and CTOL on these two routes (11 minutes and 7 minutes, respectively), it would seem unlikely that the introduction of STOL on these routes would substantially affect the volume of improved passenger rail traffic. Very little competition would be expected between STOL and improved rail on the two longest routes - Toronto-Montreal and Toronto-Ottawa - in view of the large door-to-door time savings of STOL over improved rail and comparatively small differences in door-to-door time savings of STOL over improved rail and comparatively small differences in door-to-door travel times between STOL and CTOL.
>
> Thus, with the exception of the Montreal - Ottawa and Toronto - London routes, it seems likely that improved rail service would generally serve a different market than STOL. Since these two routes would together only account for approximately 8% - 17% of the total, system-wide STOL traffic volume, it has been concluded that the proposed Corridor STOL and improved rail services can reasonably be viewed as complementary rather than competing services. The adoption of either transportation system would not significantly influence the desirability of adopting the other as well."

An appendix is given to the report. These forecasts are made without and with a STOL Service. Annual passenger forecasts have been developped for the period 1980 - 1990 for all modes.

> "Estimations of CTOL and bus traffic were based largely on the projections developed by the CTC for their Intercity Passenger Transport Study of 1970. Rail passenger volumes were estimated on the basis of 1975 CN origin destination passenger ticket lift

> figures. The 1976 projection was obtained by assuming a 10% growth rate, to reflect road speed limit changes and energy costs. Volumes for the following years up to 1980 were calculated on the assumption of an annual 3% growth rate, which was based upon the slow growth trend experienced between 1965 and 1975. Auto traffic, not estimated in the CTC study, was assumed to grow at a rate of 5% per year from 1970 levels.
>
> The CTOL air traffic projections developed by the CTC in 1970 (after the adjustments in rail traffic described above) were compared with actual traffic volumes experienced during the years 1970-1974 in order to evaluate their accuracy. The projections proved to be exceeding good for the Montreal - Ottawa route. The CTC projections were therefore used directly for this route. Table give the passenger forecast for the Montreal - Ottawa route, without a STOL service".

Traffic forecasts from that study are shown in Table A-11.

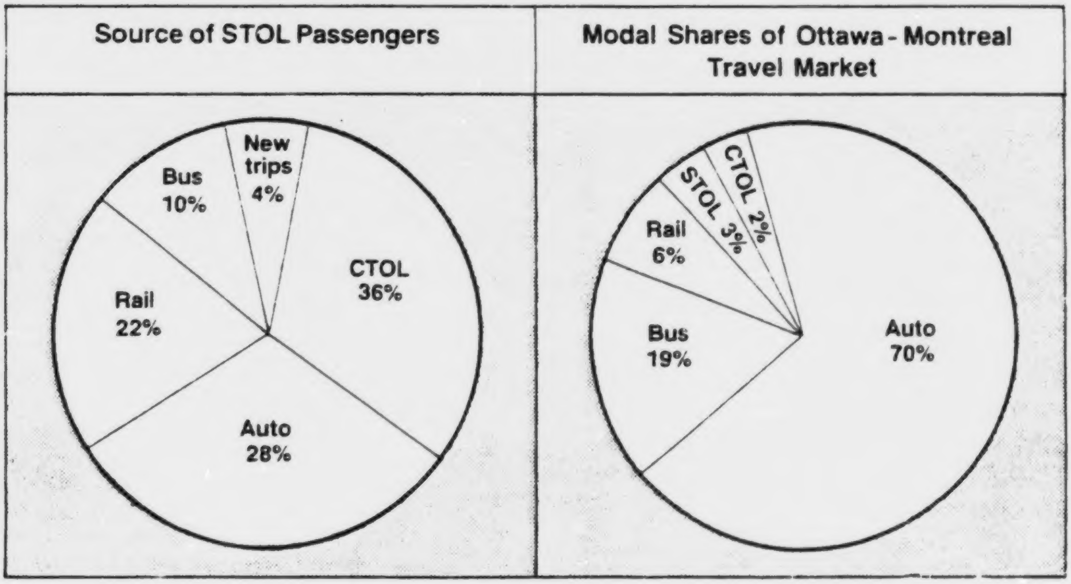


Figure A-5 Source of STOL Passengers and Modal Shares

Source: Reference 4.

Table A-11

Projected Annual One-Way Traffic Forecasts,
by Mode, 1980 - 1990
for the Montreal - Ottawa Route
(in Thousands of Passengers)

Year	CTOL	Rail	Bus	Auto	TOTAL (without Auto)	TOTAL (with Auto)
1980	147	198	995	3 986	1 340	5 326
1981	156	203	1 055	4 199	1 414	5 613
1982	165	210	1 118	4 423	1 493	5 916
1983	175	216	1 185	4 659	1 576	6 235
1984	186	222	1 257	4 907	1 665	6 572
1985	197	229	1 332	5 169	1 758	6 927
1986	208	236	1 404	5 439	1 848	7 287
1987	219	243	1 480	5 722	1 942	7 664
1988	231	250	1 559	6 021	2 040	8 061
1989	243	258	1 642	6 335	2 143	8 478
1990	256	265	1 732	6 665	2 253	8 918

Source: Reference 4.

A.5 Freight and Passengers Forecasts 1981

This report (5) issued by the Stretegic Planning Group of Transport Canada deals with transportation forecasts. Although it does not deal specifically with the Montreal - Ottawa, it gives indicators as the expected annual growth rate of demand up to 991. Forecasts are given in Table A-12 and A-13.

Table A-12

Overall Expected Growth Rate by Mode (Canada)

Mode	Expected annual growth rate (%)			
	1976-86		1986-91	
	Low	High	Low	High
Air	4,5	5,3	4,0	4,8
Rail	5,1	5,1	4,8	4,8
Bus	2,7	2,7	2,5	2,5
Auto	2,3	2,3	2,2	2,2
TOTAL	2,7	2,8	2,6	2,7

Source: Reference 5.

Table A-13

Expected Annual Growth Rate by Mode (Quebec and Ontario)

Mode	Period	Quebec	Ontario
Air	1976 - 86	3,4	4,0
	86 - 91	3,6	4,2
Rail	1976 - 86	4,9	5,1
	86 - 91	4,6	5,0
Bus	1976 - 86	2,4	2,7
	86 - 91	2,2	2,5
Auto	1976 - 86	2,0	2,3
	86 - 91	1,9	2,3
TOTAL	1976 - 86	2,5	2,8
	86 - 91	2,4	2,8

Source: Reference 5.

A.6 Alternatives to Air

This report (6) deals with the evaluation of alternatives for guided ground transport systems between Toronto, Ottawa, and Montreal. It Four systems are analyzed:

- Maglev (450 km/h);
- High speed train (260 km/h);
- Intermediate speed train (200 km/h);
- STOL service.

Travel forecasts were prepared for the evaluation of these systems, according to the report.

"The development of modal demand projections was carried out in two stages. The first stage was the development of basic total demand projections through 2025. This latter horizon was necessary to allow the Maglev system to be evaluated over a 30-year operating period, with 1996 as the first full year of operations.

The base-line 0 D data for 1980-1990 were taken from the forecasts prepared for the "STOL and SHORT HAUL Air Transportation in Canada" report.* These data were then extrapolated through 2000 using exponential decay to bring the rate of growth to 2 per cent by 2000. The resulting projections were then factored yp to account for other traffic.* The resulting values formed the basic total demand schedule used in the subsequent estimation of modal splits.

The second stage of the process was to estimate modal splits for each system. This was done by first obtaining data on the existing modal split, then developing heuristic estimates of the proprotion of traffic each new alternative might capture under each of three sets of assumptions about economic activityand petroleum availability. These modal splits were carried through to 2000. Projections of demand beyond this horizon were obtainde by assuming the rate Project of increase for each of the three new alternatives would decay exponentially to one per cent by 2025. Total demand projections for this period were not made."

* Other traffic includes traffic for intermediate points (Mirabel), through traffic and induced traffic.

Results of the study concerning the Montreal - Ottawa Corridor are given in Table A-14. However, as staled before, these forecasts do not include other traffic such as Montreal - Mirabel and Mirabel - Ottawa.

Table A-15 shows the unfactored travel demand flows for each O.D. pair from 1980-2000 in the Montreal - Ottawa Corridor, these basic flows must be factored to reflect through traffic and induced demand. Tables A-16, A-17 and A-18 show the factored by-link flows at five-year intervals for Maglev, HST and ISR levels of induced traffic, respectively.

A scenario approach to the development of modal split estimates was selected to minimize the methodological problems that invariably accompany an attribute-modelling approach. Three basic scenarios have been defined.

(1) A status quo scenario, which basically assumes that no serious dislocation of the existing trends in economic activity, energy availability and price will occur over the period 1980-2000. Under this assumption, the gross travel demand corresponds to the levels forecast in Table A-16.

(2) An economically optimistic scenario, in which the supply of petroleum energy is essentially unrestricted at current real prices. Under this assumption, the gross travel demand is 10 per cent higher than that forecast in Table A-16.

(3) An economically pessimistic scenario, in which the physical supply of petroleum energy is dramatically restricted by 1990, resulting in gasoline rationing and a restriction on intercity air travel at distances under 500 miles. Under these circumstances, the gross travel demand will fall 20 per cent short of the levels forecast in Table A-16.

Table A-17 summarizes the approximate modal splits for each city pair in 1977.

Tables A-18, A-19, and A-20 summarize the modal split estimated for each scenario.

Table A-14

Total Travel Demand Forecasts
for Montreal-Ottawa, 1980-2000*
(number of one-way trips x 10^6)

Year	Montreal - Ottawa
1980	5,326
1981	5,613
1982	5,886
1983	6,235
1984	6,572
1985	6,927
1986	7,287
1987	7,664
1988	8,061
1989	8,478
1990	8,918
1991	9,325
1992	9,713
1993	10,082
1994	10,431
1995	10,761
1996	11,072
1997	11,363
1998	11,636
1999	11,891
2000	12,129

* 1980-1990: after Appendix A, p. A.4, "STOL and SHORT HAUL Air Transportation in Canada", Transport Canada, July 1978.
1991-2000: using exponential decay to a terminal rate of two per cent per year.

Source: Reference 6.

Table A-15

Unfactored Travel Demand by City Pair, 1980-2000
(millions of annual one-way trips)

Year	Ottawa to Mirabel	Ottawa to Montreal	Mirabel* to Montreal
1980	0,221	5,326	6,137
1981	0,240	5,613	6,523
1982	0,262	5,886	7,152
1983	0,287	6,235	7,877
1984	0,313	6,572	8,634
1985	0,344	6,927	9,773
1986	0,375	7,287	10,722
1987	0,405	7,664	11,701
1988	0,436	8,061	12,649
1989	0,464	8,478	13,427
1990	0,492	8,918	14,154
1991	0,520	9,325	14,822
1992	0,545	9,713	15,447
1993	0,569	10,082	16,002
1994	0,590	10,431	16,495
1995	0,611	10,761	16,967
1996	0,630	11,072	17,349
1997	0,647	11,363	17,690
1998	0,678	11,891	18,339
2000	0,691	12,129	18,657

* Includes commuter traffic to airport region.

Source: Reference 6.

Table A-16

Gross Travel Demand by City Pair, 1980-2000
(millions of annual one-way trips)

System	City-Pair	1980	1985	1990	1995	2000
MAGLEV	Ottawa - Mirabel*	0,221	0,344	0,492	0,611	0,691
	Ottawa - Montreal	6,764	8,797	11,326	13,666	15,404
	Mirabel - Montreal	6,295	10,038	14,547	17,406	19,110
HIGH SPEED RAIL	Ottawa - Mirabel*	0,221	0,344	0,492	0,611	0,691
	Ottawa - Montreal	6,771	8,728	11,237	13,559	15,283
	Mirabel - Montreal	6,256	9,972	14,449	17,296	18,997
INTERMEDIATE SPEED RAIL	Ottawa - Mirabel*	0,221	0,344	0,492	0,611	0,691
	Ottawa - Montreal	6,658	8,659	11,148	13,451	15,161
	Mirabel - Montreal	6,216	9,905	14,350	17,187	18,883

* No scale factors applied; demand reflects levels of international air travel, not attractiveness, etc. of ground modes.

Source: Reference 6.

Table A-17

1977 City Pair Modal Splits

City Pair	Bus	Rail	CTOL Air	Automobile
Ottawa - Mirabel *	0,012	0,000	0,000	0,988
Ottawa - Montreal	0,187	0,037	0,028	0,748
Mirabel - Montreal	0,080**	0,000	0,000	0,920

* Subjective estimates
** Includes taxis, limousines services, etc.

Source: Reference 6.

Table A-18

Modal Splits, Status Quo Scenario

City Pair	Modal Share			
	Maglev	Bus	CTOL Air	Automobile
Ottawa - Mirabel	0,227	0,012	0,000	0,761
Ottawa - Montreal	0,153	0,166	0,005	0,676
Mirabel - Montreal	0,156	0,80	0,000	0,764
City Pair	HSR	Bus	CTOL Air	Automobile
Ottawa - Mirabel	0,257	0,012	0,000	0,731
Ottawa - Montreal	0,199	0,129	0,011	0,661
Mirabel - Montreal	0,166	0,80	0,000	0,754
City Pair	ISR	Bus	CTOL Air	Automobile
Ottawa - Mirabel	0,188	0,012	0,000	0,800
Ottawa - Montreal	0,192	0,121	0,021	0,666
Mirabel - Montreal	0,129	0,080	0,000	0,791

Source: Reference 6.

Table A-19

Modal Splits, Optimistic Scenario

City Pair	Modal Share				
	Maglev	Bus	STOL Air	Automobile	CTOL Air
Ottawa - Mirabel	0,307	0,009	0,000	0,684	0,000
Ottawa - Montreal	0,297	0,112	0,119	0,468	0,004
Mirabel - Montreal	0,186	0,066	0,000	0,748	0,000
City Pair	HSR	Bus	STOL Air	Automobile	CTOL Air
Ottawa - Mirabel	0,238	0,011	0,000	0,751	0,000
Ottawa - Montreal	0,247	0,112	0,149	0,486	0,006
Mirabel - Montreal	0,133	0,066	0,000	0,801	0,000
City Pair	ISR	Bus	STOL Air	Automobile	CTOL Air
Ottawa - Mirabel	0,258	0,009	0,000	0,733	0,000
Ottawa - Montreal	0,209	0,116	0,116	0,544	0,013
Mirabel - Montreal	0,120	0,062	0,000	0,818	0,000

Source: Reference 6.

Table A-20

Modal Splits, Pessimistic Scenario

City Pair	Modal Share			
	Maglev	Bus	CTOL Air	Automobile
Ottawa - Mirabel	0,346	0,160	0,000	0,494
Ottawa - Montreal	0,205	0,421	0,000	0,374
Mirabel - Montreal	0,138	0,402	0,000	0,460
City Pair	ISR	Bus	CTOL Air	Automobile
Ottawa - Mirabel	0,405	0,101	0,000	0,494
Ottawa - Montreal	0,301	0,325	0,000	0,374
Mirabel - Montreal	0,138	0,402	0,000	0,460

Source: Reference 6.

A.7 Intercity Passenger Transport Energy Efficiency

This report, entitled "Intercity Passenger Transport Energy Efficiency: Data Base and Case Study" was prepared by the Department of Civil Engineering, Carleton University, for Strategic Studies Branch, Transport Canada and published in Ottawa in 1979.

This reports (7) focuses on intercity passenger transport energy efficiency with a data base developped for the Quebec Windsor Corridor.

Travel demand and modal splits used in this report are based on 1976 O-D data and also on 1985-1990 projections reported in Transport Canada document on STOL and Short Haul Air Transportation.

The reports examiner the impact of several scenarios of improvements on the different transport systems, which lead to identify energy demand changes (Table A-21). Results of the analysis for the Toronto - Ottawa - Montreal Corridor are shown in Table A-22.

Table A-21

Toronto-Ottawa-Montreal Transport System - 1976
Summary of Scenarios

Scenario	
Scenario 1 (Base)	1976 infrastructure, technology and load factors. January to April 1976 Air Transit between Ottawa and Montreal excluded and traffic attracted from other modes (96% of Air Transit traffic) allocated to their original modes. Four percent of Air Transit traffic, which was new travel generated, is excluded.
Scenario 2	1976 infrastructure and technology (i.e. as represented by Scenario 1). Increased load factors (CTOL: 75% on all links, Rail: Toronto-Montreal-75%, Other links-60%; Bus: 75% on all links; Auto: 60% on all links).
Scenario 3	1976 infrastructure (same as Scenario 1) and load factors. 1976 technology for all modes except rail. For rail, LRC technology assumed.
Scenario 4	1976 infrastructure and technology except LRC for rail assumed (same as Scenario 3). Increased load factors assumed (same assumption of load factors as in Scenario 2)
Scenario 5	1976 infrastructure and technology except LRC for rail assumed (same as Scenarios 3 and 4). 25% of CTOL traffic shifted to rail. 1976 load factors except increased load factors for rail (75% for Toronto-Montreal, 60% for Toronto-Ottawa and 60% for Ottawa-Montreal).
Scenario 6	1976 infrastructure. STOL service on all links. 1976 load factors for all modes. Conventional rail technology.

Source: Reference 7.

References

1. Soberman, R., et al. "Intercity Passenger Transport Study", Research Branch, Canadian Transport Commission, Transport Canada, Ottawa, 1970.

2. Transportation Development Agency, "Mode Choice for Intercity Passenger Travel Montreal-Ottawa: A working paper", Report TP 234, Transport Canada, Ottawa, 1979.

3. Smith, T., "Passenger Transportation between Montreal and Ottawa, 1973-76: An analysis of the impact of the Air transit STOL Demonstration Service on the passenger volumes of other modes, including the private automobile", Research Report TP 1409, Research and Development Centre, Transport Canada, Montreal, 1977.

4. Air Administration "STOL and Short Haul Air Transportation in Canada", Report TP 1494, Transport Canada, Ottawa, 1978.

5. Strategic Planning Group, "Freight and Passenger Forecasts, 1981", Report TP 2957, Transport Canada, Ottawa, 1982.

6. Canadian Institute of Guided Ground Transport, "Alternatives to Air: a feasible concept for the Montreal-Ottawa-Toronto Corridor", Report TP 2667, Transportation Development Centre, Transport Canada, Montreal, 1980.

7. Department of Civil Engineering, Carleton University, "Intercity Passenger Transport Energy Efficiency: Data Base and Case Study", for Strategic Studies Branch, Transport Canada, Ottawa, 1979.

B. TECHNICAL DOCUMENTATION ON MAGLEV

This section provices complementary documentation to Chapter 2 by presenting summaries of six relevant articles on Maglev that were recently published in German.

Each section corresponds to a reference in the list at the end of the appendix.

B.1 Vehicle Concept

An important function of the tests conducted at the Emsland facility is to prove that, using magnetic levitation technology, an attractive and economic transportation system for high speed passenger transport can be realized.

The TR 06 vehicle tested consists of two identical sections which are mechanically coupled. Each section is carried by four bogies which are flexibly connected to each other, and which are mechanically connected by a secondary spring suspension to the car body. The two-section vehicle has an overall length of 54,2 m, a width of 3,7 m and a height of 4,2 m. The empty weight is 102,4 t, the number of passenger seats being 192.

The body is manufactured of sandwich plates riveted to an aluminum structure. On each side of the vehicle, three double-hinged doors are installed. The seats are made of glass fiber, each row having two or three seats. The first row can be swung up for physically handicapped passengers or luggage. Each section is individually equipped with: air conditioning, coupling, driver's cockpit, equipment lockers, lighting and acoustic information system, and safety devices like emergency brakes and emergency slide for evacuating passengers.

The suspension and guidance system works on the principle of magnetic attraction by controlled electro-magnets. It is designed using a modular approach. The main part of the suspension and guidance system is the individual "magnet wheel". It consists of the following components: magnet, sensors, controls, magnetic current regulating unit, control and monitoring equipment.

The emergency braking system works two ways: either by electro-hydraulic friction brakes or by setting down the vehicle on its sliding skids. On-board power is provided by a non-contact system, a socalled linear generator. On-board power supply is provided from the linear generator via rectifiers to the accumulators.

The driver's cockpit is equipped with the operational signals and an alphanumeric display, which indicates the exact operating conditions of the vehicle equipment and the on-board control system.

On-board computers control and monitor the following vehicle equipment and coordinate it for both sections: guidance/levitation system, secondary suspension, braking system, energy supply, hydraulics, pneumatics, air conditioning, heating, air conditioning, doors and lighting.

B.2 Energy Consumption of Magnetic Levitation Systems

In order to judge the energy consumption, a measure has to be chosen which determines the characteristic values influencing the consumption and which also allows the system to be compared with other energy-consuming systems.

The common measure of comparison for transport and traffic systems is the primary energy consumption, which refers to the transport performance, that is the number of persons transported over a defined distance with a given amount of energy. For calculating the energy consumption of Maglev, a method was found that takes into account the trapezoid profile of vehicle movement. Considering phases of constant acceleration, steady speed and constant deceleration, the movement profile can easily be determined mathematically.

The trapezoid traction profile can be divided into two phases in order to calculate the energy consumption: the phase of acceleration and the phase of constant speed. In the braking phase, no energy is consumed. In the constant speed phase, the product of drag and covered distance is used to calculate the energy consumption. In the phase of acceleration, different portions have to be considered: the energy needed for accelerating the mass of the vehicle and the energy needed to cope with increasing drag as a result of increasing velocity.

The calculation basis, the drag curve, was obtained from a Maglev vehicle model, by aerodynamic measurements in wind tunnels. The inductive braking effect of the levitation and guidance system was also calculated from the results of the experiments. A number of parameters were taken into consideration: maximum final speed of 150 to 400 km/h, distance between stations from 50 to 150 km, average accelerations and decelerations from 0,3 to 0,5 m/s^2 and load factors from 25 to 100%. The calculations show that maximum speed has a high influence on the energy consumption: doubling the maximum speed means doubling the energy consumption.

Travelling distance and acceleration have only little influence on energy consumption. It can be stated that, at a maximum speed of 400 km/h, the Maglev needs as much primary energy as a car at 150 km/h. The specific primary energy consumption of a short haul aircraft at 900 km/h is about twice as much as that of Maglev at 400 km/h. The specific energy consumption of an intercity train at 160 km/h is 25% higher than for Maglev at the same speed.

B.3 Long-Stator Synchronous Linear Motor

The propulsion system of the TR 06 vehicle consists of an iron-cored long-stator synchronous motor. On the underside of the track, the long-stator linear induction motors, comprising a three-phase stator winding and stator plates connected in series, are fixed on each side. Two static inverters located in a substation in the test center feed a three-phase current, variable in frequency and voltage, into the long-stator winding. Thus a travelling field is generated, which moves synchronously with the vehicle. The levitation magnets of the Maglev train are arranged as alternating magnetic south and north poles, in order to provide the DC exciter field for the synchronous long-stator linear motor.

In order to limit motor reactance and therefore the required voltage, the long-stator motor is subdivided into several feeder sections which are connected to the power supply consecutively by vaccuum circuit breakers. Each separately-fed section is 320 m long on high-speed track sections and 3 000 m elsewhere. Depending on the vehicle position, the inverters will be connected alternatively to the winding sections to assure a jerkless transition to the next section. The motive power will thus be transmitted inductively to the levitated vehicle; therefore no power collectors are used. The energy for the on-board auxiliaries will be supplied by linear generators integrated into the poles of the levitation magnets.

The stator consists of single 1 000 m long steel packs made of 360 sheets of magnetic steel with a 0,5 mm width, which are fixed along the guideway.

The three-phase stator winding fastened below the steel sheet packs consists of deformed screened one-core cables, which are fixed with mounting straps in slots. The main electrotechnical components of the iron-cored synchronous linear motor are:

- power supply unit in the substation;
- feeder cable and circuit breakers for feeder sections;
- control and monitoring of the propulsion system.

Conversion of the power delivered by the Utility grid is provided by frequency converters. Power feeding is achieved by two converters for redundancy. These two converters feed, in parallel, the intermediate circuit which the frequency converters for the connection to the guideway are connected to. The frequency converters produce, from the DC voltage, a 3-phase-current with adjustable voltage and frequency.

The layout of the propulsion system is mainly influenced by the vehicle drag. It consists of three components:

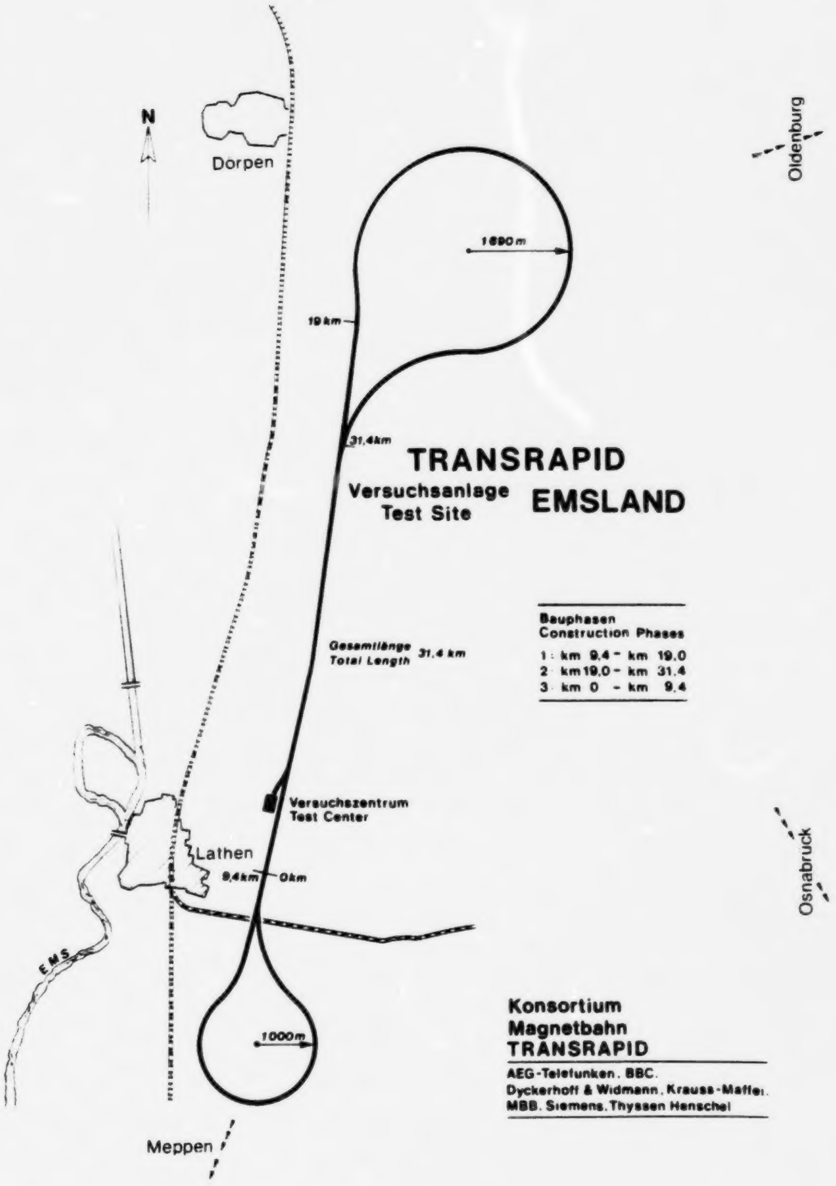
- aerodynamic drag;
- drag due to eddy currents in the guidance rails (generated by guidance magnets);
- drag due to braking effects of the linear generator.

B.4 Emsland TransRapid Test Facility

The development of electro-magnetically suspended transportation systems has been pursued since 1970 in the Federal Republic of Germany. The decision was made in 1978 to set up a test center for the electro-magnetic high-speed transportation system for semi-operational tests. The objectives of the test facilities are: to test the system under pratical consitions in continuous operation; to prove security, environmental compatibility and attractiveness for the user, availability, reliability; to indicate and forecast operating costs and to prove efficiency.

The test track has a length of 31,5 km, including a straight line of 12 km and two loops with radii of 1000 m and 1690 m (Figure B-1). The horizontal curves are superelevated up to 12° and allows speeds up to 215 and 280 km/h. The single guideway is continuously elevated. Foundations and supports consist of concrete, the beams to be constructed of concrete or steel. The beams are equipped for the long-stator propulsion system. Two flexible switches will be tested. The TransRapid test vehicle TR 06 is equivalent to a series vehicle. It consists of two sections connected mechanically and electrically.

For propulsion, the linear synchronous long-stator motor is used. An inverter controls the thrust by variation of frequency and voltage. Power is supplied by the 110 kV network. The linear motor is used both for propulsion and non-contact braking. A mechanical brake serves as emergency brake in case of failure of the electrical brake.



N
Dorpen
Oldenburg
1690 m
19 km
31,4km
TRANSRAPID
Versuchsanlage
Test Site
EMSLAND
Bauphasen
Construction Phases
1: km 9,4 - km 19,0
2: km 19,0 - km 31,4
3: km 0 - km 9,4
Gesamtlänge
Total Length 31,4 km
Versuchszentrum
Test Center
Lathen
9,4km
0km
Osnabruck
EMS
1000m
Konsortium
Magnetbahn
TRANSRAPID
AEG-Telefunken, BBC.
Dyckerhoff & Widmann, Krauss-Maffei,
MBB, Siemens, Thyssen Henschel
Meppen

Figure B-1 MAGLEV Test Track in Emsland

The information system of the test facility has three main tasks:

- to guarantee the system operations;
- to control and supervise the phases of operation;
- to collect, store, document and evaluate test data and general operational data.

The operation of the vehicle, guideway and substation is controlled from the central panel in the test center.

Tests will be performed for 18 hours daily, with cycles of 30 minutes continously repeated. In a cycle, the vehicle coves a distance of 77 km.

B.5 Maglev Guideway at the Emsland Test Facility

Once completed, the test track will have a length of 31,5 km (Figure B-1). A continuously-elevated single guideway is used. Foundations and columns are made of concrete, the guideway beams are made of concrete or steel. The normal span of the beams is 25 m. The beams will be equipped for the long-stator propulsion system. Two flexible switches of different designs will be tested.

Dyckerhoff & Windmann is responsible for the concrete guideway, the guideway substructures and the construction service road. Krauss-Maffei is responsible for the technology, for installing equipement on the concrete guideway, and for the switches. The steel guideway with equipment, soil mechanics, alignment and survey are covered by Thyssen Industrie AG Henschel.

Construction of the concrete guideways was started in 1980. Because a very high accuracy is required for the levitation and guidance rails, the production of the beams and the installation of the equipment are carried out separately. Due to stringent tolerances, conditions of the sub-soil are decisive. Because of these conditions, pile foundations were used. A-shaped supports were specially developed.

The concrete beams have a one-cell box-type cross section. The height of the beam for a normal span is 1,8 m. The prefabricated concrete parts are manufactured close to the guideway in a factory at the site. Openings are provided in the beam for subsequently fastening guidance rails and stator equipment.

The emergency rails on the surface of the beam (elevated concrete stripes) are finished by a milling cutter after installation of the beam. In order to mount the guideway equipment, mobile devices are developed, forming a work train known as "Verlegezug". It consists of four vehicles: feeder for adjustment and vehicle with milling cutter.

The steel guideway is 5 km long and designed as a two-span-system. The substructures, in principle, correspond to the substructures of the concrete guideway. Completion of the beam is done in the workshop with the usual accuracy in steel construction. The guideway equipment, produced with high accurary, is fixed to the steel beam with a mounting device.

In the first stage of construction, the Emsland Test Faciity is equipped with two switches which allow a maximum speed of 400 km/h in a straight direction and 200 and 100 km/h, respectively, in the branch direction. Switching time for one working cycle is 20 seconds. In principle the switch is constructed as a continuous flexible steel beam (about 67 or 132 m). This beam, which is without tension in the straight position, is elastically bent by mechanical devices which are fixed at several supports. The branching point consists of a fixed support. The guideway equipment is mounted on sleeper-like devices on the surface of the steel beam.

B.6 Geometric Design of High-Speed Maglev Guideways

To determine the route parameters, the special characteristics of the electromagnetic levitation system have to be considered besides the usual requirements of comfort for high-speed guided traffic. The active track guidance affects the curve radii; the contact-free propulsion and braking systems affects the longitudinal gradient. From the distributed loads and the vehicle embracing the track follow the characteristic track element: elevated guideway. The route parameters are defined on the following basis: passenger and freight service run on a common track in mixed operation. The maximum speeds are 300 and 400 km/h respectively.

In addition to sinusoidal transition curves and ramps, standard radii of 4 400 m are important elements. Such a small radius results from the 12° superelevation that is possible with Maglev vehicles. The maximum longitudinal gradient is 3,5%; the rounding out of the change in gradient is circular. Vertical and horizontal curves can coincide just as rounding out and transition curves.

The clearance between track centres, for a 4,2 m wide vehicle at a maximum speed of 400 km/h, is 5,6 m on an open line, 7,6 m in a tunnel due to the specific aerodynamic conditions and 7,3 m at by-passes. The most important standard cross sections used for Maglev technology are: elevated guideway at grade, cuts with slopes, cuts with retaining walls, and tunnels.

It is concluded that, due particularly to the special characteristics of the contact-free EMS technique, with the resulting flexibility in the selection of route elements such as radius of curvature, maximum longitudinal gradient and supports, the average route investment costs can be less than for conventional high-speed railway routes.

References

1. Peter Shcwärzler, Jürgen Borchert, Günter Stein metz, Peter Knorr, and Karl Dreimann, "Trans Rapid 06 Vehicle Concept", ZEV-Glasers Annelen, 105, 7/8, (1981)

2. Willi J. Mayer, "Energy Consumption of Magnetic Levitation Train Systems", Ersenbahn technische Rundschau, 11, (1981)

3. Claus-Peter Parsch and Hans-Georg Raschbichler, "The Iron-Cored Long Stator Synchronous Motor for the Emsland Trans Rapid Test Facility", ZEV-Glasers Annalen, 105, 7/8, (1981)

4. Dieter Hilliges, Peter Mölzer, Hans-Geor Raschbichler, and Rudolph Zurek, "The guideway of the Emsland Trans Rapid Test Facility", ZEV-Glasers Annelen, 105, 7/8, (1981)

5. Erich Eitlhuber, "Emsland Trans Rapid Test Facility" ZEV-Glasers Annalen, 105, 7/8, (1981)

6. Rudolph Surek and Peter Mölzer, "Route Elements for High-Speed Guideways for Electromagnetic Levitation Systems" Eisenbahn technishche Rundschan, 4, (1977)

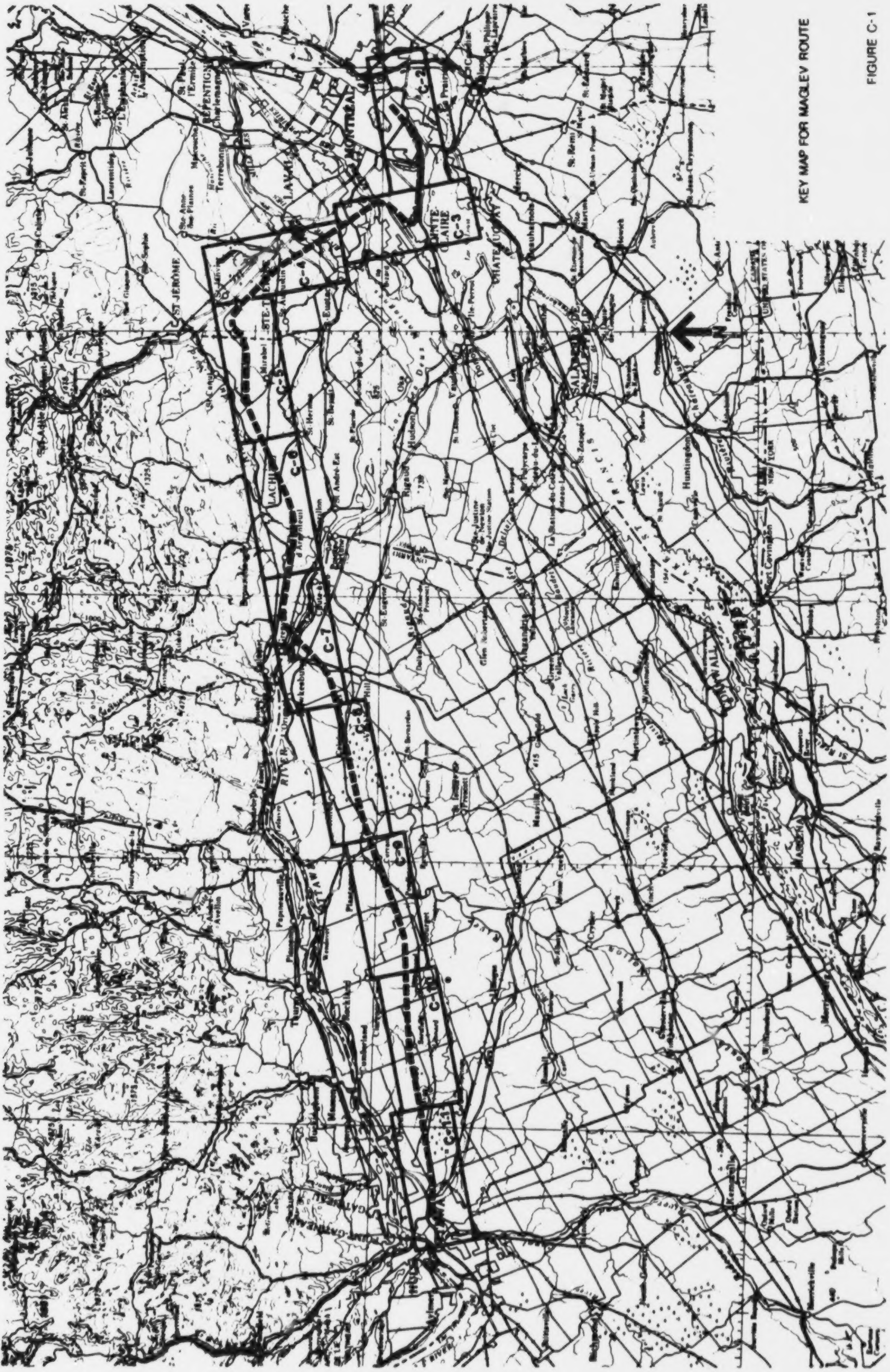
C. DESCRIPTION OF THE MAGLEV ROUTE

The objective of this appendix is to provide complementary information to the summary description of the Maglev route that was presented in Section 4.4.

This appendix consists in part of a series of topographical maps at the 1:50 000 scale, on which the alignment chosen for the Maglev route is shown in plan; a short explanatory text accompanies each map and outlines the key features of the alignment in that section.

With each map, a drawing shows the alignment in profile; as the terrain is fairly level between Montreal and Ottawa, an exaggerated vertical scale of 1:1000 has been chosen to better illustrate the vertical variations of the terrain and the alignment.

The Maglev Key Map (figure C-1) consists of a 1:500 000 topographical map showing the area from Montreal to Ottawa via Mirabel. The alignment in plan is overlaid on that base map. Also, areas covered by individual maps at the 1:50 000, which are described in the following sections, are shown on the key map.



MONTREAL
LAVAL
ST-JEROME
STE-THERESE
LACHUTE
SALABERRY-DE-VALLEYFIELD
CHATEAUGUAY
CORNWALL
HULL
OTTAWA RIVER
ST. FRANCIS
C-1
C-2
C-3
C-4
C-5
C-6
C-8
C-9
C-10
C-11
N

KEY MAP FOR MAGLEV ROUTE

FIGURE C-1

C.1 Montreal Downtown Area (Figure C-2)

Starting from the Montreal terminal at Windsor Station, the route selected follows the CP right-of-way (Subdivision Vaudreuil) towards Dorval through the suburban cities of Westmount, Montreal West, Saint-Pierre, Lachine, and Dorval.

The Maglev route thus leaves Windsor Station in a southwesterly direction; the guideway would be built on the north side of the right-of-way, within it. As there is no space for building the Maglev guideway at grade on either side of the right-of-way, the guideway would have to be built over the existing tracks and structures, signal masts and bridges as well as two highway overpasses.

Consequently, the guideway would be 9 m above rail in Windsor Station. Soon after leaving it, the guideway would climb to 15 m above rail for the purpose of clearing access and egress ramps to/from Autoroute 20 at Guy Street, at km 0,9 and km 1,0.

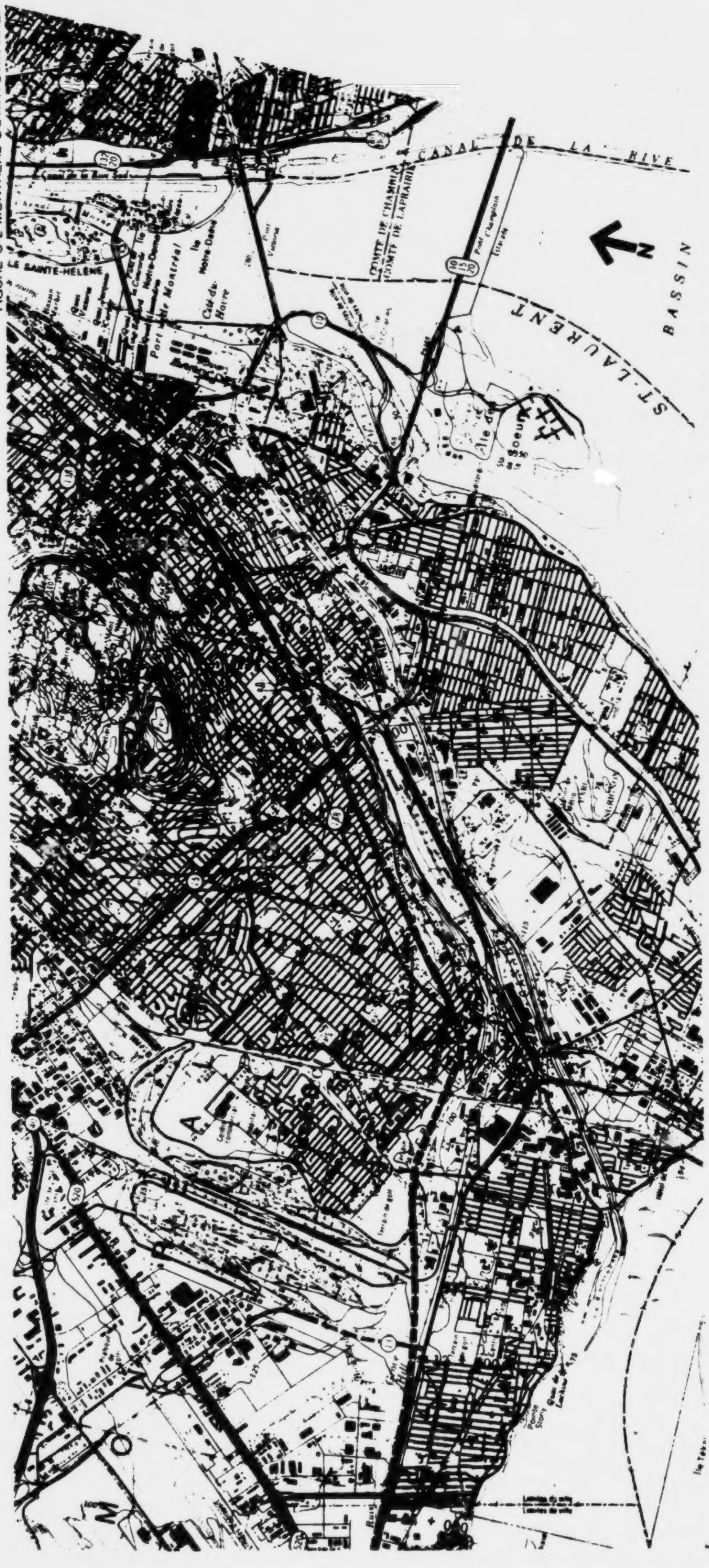
After crossing these overpasses, the Maglev guideway descends back to 9 m above rail, which ensures the necessary vertical clearance for other structures, primarily signal bridges.

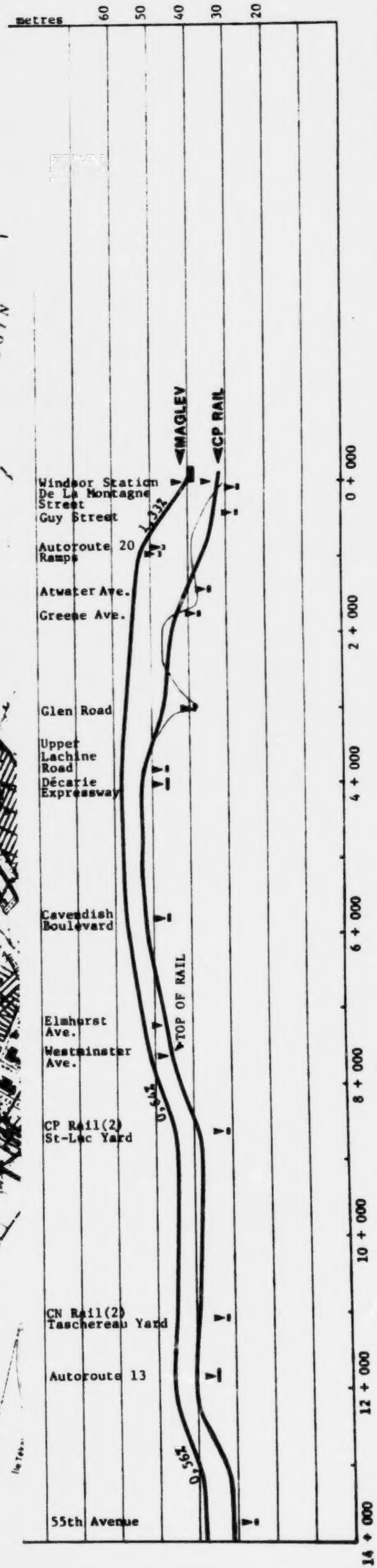
For the rest of the route, shown on Figure C-2, the alignment remains at that level and passes over existing grade separations and grade crossings with the following major cross roads, as well as over other features: Atwater Tunnel, Glen and de Courcelle Roads in Westmount, CP Westmount Station, Autoroute Décarie, Girouard Avenue and Cavendish Boulevard in Montreal, Elmhurst and Westminster Avenues in Montreal West, CP Montreal West Station.

The Maglev guideway then crosses over the tracks in CP Subdivision Park Avenue, runs along the South Side of Meadowbrook Golf Club, passes over the tracks entering CP Côte-Saint-Luc Yard, next over the entrance track to CN Taschereau Yard, then over Autoroute 13, CP Grovehill suburban station, and 55th Avenue in Lachine.

The first noteable curve in that part of the route is found in Montreal West; it is centered around a point at km 7+900; its 640 m radius allows a safe speed of 150 km/h with a 9° superelevation: for such short radii, speed through curves is limited by technical parameters that are more constraining than comfort limitations. That curve is followed by a tangent of more than 1 km. Then, there is a curve in the opposite direction, with a 570 m radius allowing a speed of 140 km/h, centered at km 9+700. Following that, the alignment is almost straight.

FIGURE C-2 MONTREAL DOWNTOWN AREA


CANAL DE LA RIVE
BASSIN
ST. LAURENT
N
ILE SAINTE-HÉLÈNE



C.2 West Island Area (Figure C-3)

Entering this area, the guideway is still built 9 m above rail on the north side of the CP right-of-way. The straight section ends at km 17 + 350, after passing near the CP suburban station in Dorval and over Autoroute 520.

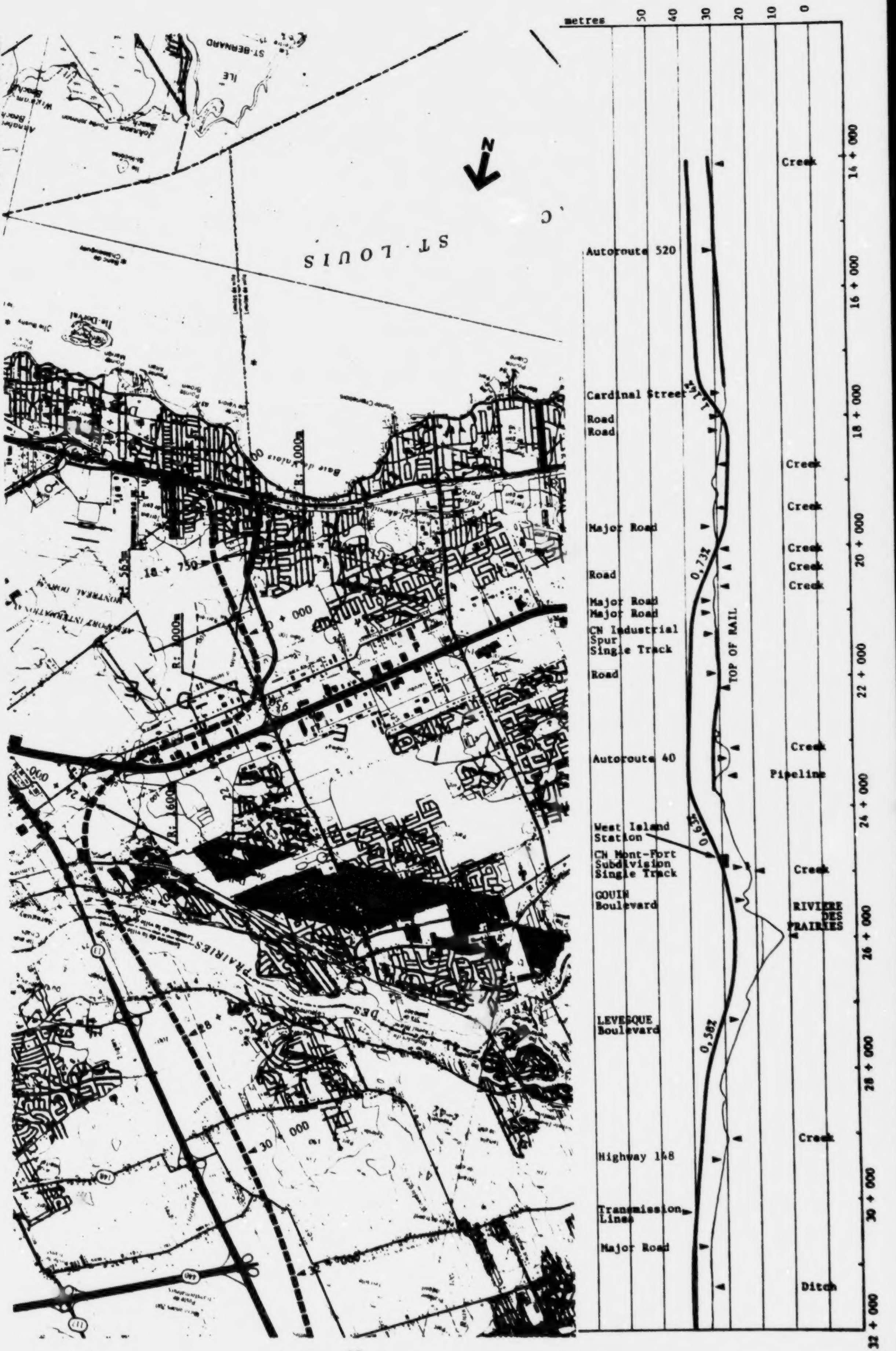
The route must then turn toward the correct direction to reach Mirabel along Autoroute 13. The construction of tunnels along Autoroute 13 in Dorval or under runways of Dorval Airport was rejected because of excessive engineering difficulties (tunnels would have to pass under runways near the point of maximum touchdown impact, or under large aircraft maintenance buildings) and/ or construction costs that would be prohibitive (with respect to the advantages of such an alignment).

The best alignment was found to be along the western boundary of the airport property. The Maglev guideway would thus leave the CP right-of-way somewhat east of Montée des Sources, in a 563 m radius curve over Cardinal Avenue. That curve, centered at km 17+700, allows a speed of 140 km/h due to technical constraints.

After curving, the Maglev route proceeds through a small park, as this would entail the minimum amount of expropriation: four single-family houses, one or two 20-unit apartment houses, and a small elementary school that could easily be relocated or rebuilt nearby.

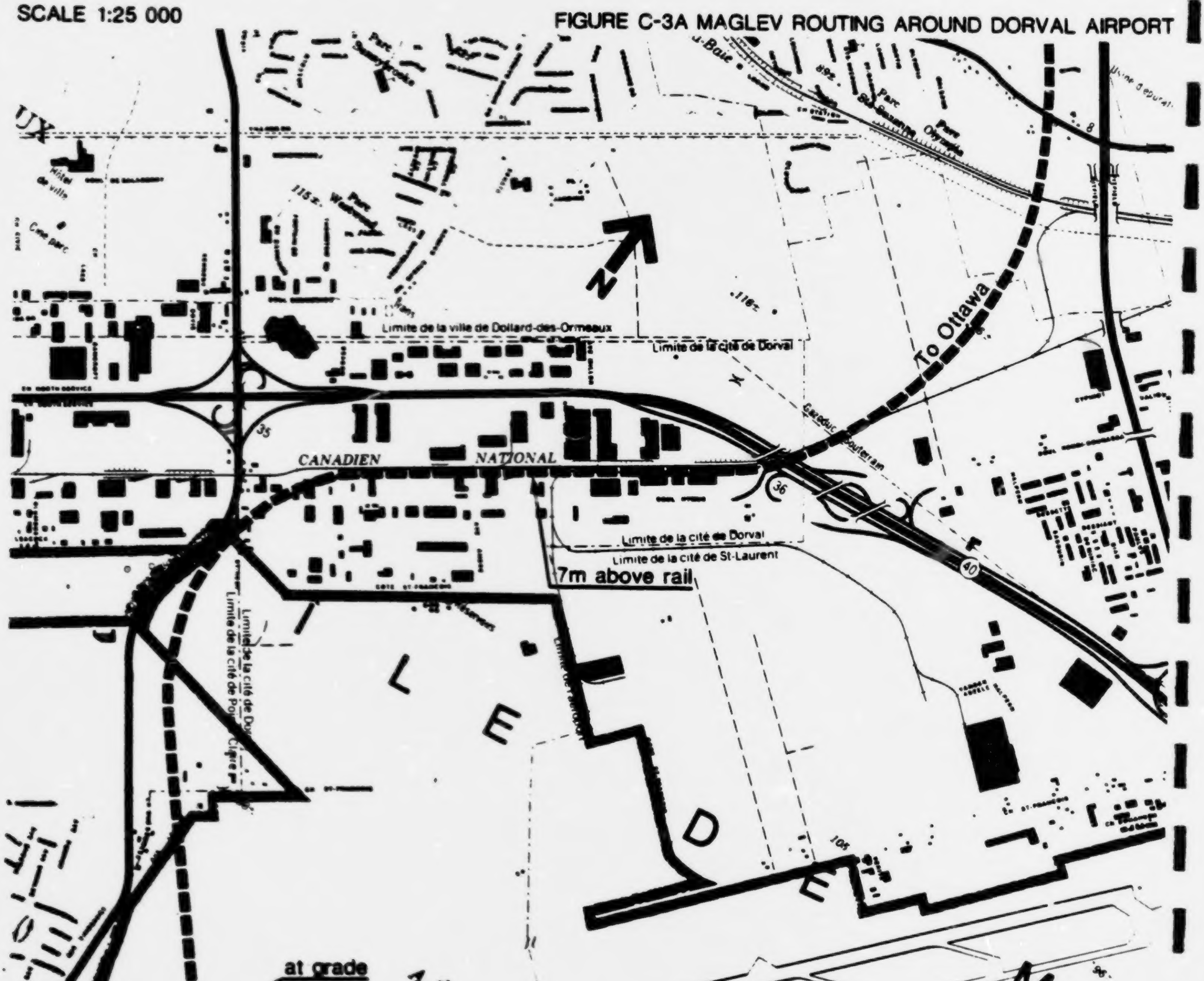
In that area, to minimize intrusion, the Maglev right-of-way is only 10 m wide. To comply with airport building height restrictions, the guideway must progressively descend to ground level; this is done at a 3% grade. To further minimize noise and visual impacts, when at or near ground level, the guideway could be covered by a transparent or translucid rigid plastic canopy, somewhat like the Sapporo Metro. Details of part of the route in Dorval are shown in Figure C-3a.

FIGURE C-3 DORVAL AREA


metres
50
40
30
20
10
0
Creek
Autoroute 520
Cardinal Street
Road
Road
Creek
Creek
Major Road
Creek
Creek
Road
Creek
0.73%
Major Road
Major Road
CN Industrial Spur Single Track
TOP OF RAIL
Road
Autoroute 40
Creek
Pipeline
West Island Station
0.63%
CN Mont-Fort Subdivision Single Track
Creek
GOUIN Boulevard
RIVIERE DES PRAIRIES
LEVESQUE Boulevard
0.58%
Creek
Highway 148
Transmission Lines
Major Road
Ditch
14 + 000
16 + 000
18 + 000
20 + 000
22 + 000
24 + 000
26 + 000
28 + 000
30 + 000
32 + 000
ST. LOUIS
ILE ST-BERNARD
N
18 + 750
R. 6000
R. 1600
22 +
28 +
30 + 000
32 + 000
PRAIRIES
DES

SCALE 1:25 000

FIGURE C-3A MAGLEV ROUTING AROUND DORVAL AIRPORT


To Ottawa
7m above rail
at grade
7m above rail
CANADIEN NATIONAL
AÉROPORT INTERNATIONAL DE MONTRÉAL DORVAL
Limite de la ville de Dollard-des-Ormeaux
Limite de la cité de Dorval
Limite de la cité de Dorval
Limite de la cité de St-Laurent
Gazoduc souterrain
Gare Strathmore
N
L E D E M C
DORVA
35
36
40
520

Leaving the residential area, a reversed curve of 1000 m radius must be introduced around km 18+750, in order to clear the radar zones northwest of the airport: the guideway follows the western edge of Dorval Airport, until it reaches the Hymus Boulevard Industrial Park.

At that point, the Maglev route makes a 90° turn to follow the CN Doney Spur that is parallel to Hymus Boulevard and Autoroute 40. Between that 90° curve (1000 m radius, 150 km/h, centered at km 20+950) and the residential area, the passes over one minor road and two major ones. The curve could require the demolition of three or four small industrial buildings.

The Maglev route follows the Doney Spur for approximately 2000 m, on a tangent: the guideway is built with a clearance of 9 m above the tracks on the south side of the rail right-of-way.

Then starts a 105° curve, which has a 1 600 m radius and is centered at km 24, allowing a speed of 245 km/h. That curve will take the Maglev guideway over the Doney Spur track, over Autoroute 40, CN Subdivision Monfort and Henri-Bourassa Boulevard.

On each side of Gouin Boulevard, which runs along the Rivière des Prairies on Montreal Island, a few residential buildings will have to be expropriated, even if the right-of-way created for Maglev is only 10 m wide. The difficulties will be compounded by the presence of protected forest areas.

Between Gouin Boulevard and CN Subdivision Monfort, the Maglev suburban station will be built between the guideway and Autoroute 13. Environmental difficulties will be significant.

For crossing Rivière des Prairies, which is 600 m from bank to bank at that point, no special structure will be necessary, as standard spans are available to 72 m.

From that point until it leaves the West Island Area, the Maglev route is nearly parallel to Autoroute 13, and runs from 300 to 800 m west of it. That alignment was selected to minimize expropriation and to reduce the height of the guideway columns.

C.3 Laval - North Shore Area (Figure C-4)

In the first part of this area, to the East on Figure C-4, the Maglev route follows Autoroute 13. After crossing Rivière des Mille Iles, the Maglev route crosses Highway 344, then Autoroute 13, and Autoroute 640, proceeding toward Autoroute 15.

As when crossing Laval, the Maglev route will follow an expressway (in this case, Autoroute 15) at a sufficient distance to avoid any interference with the grade-separation structures that carry cross roads over the expressway, in an alignment selected to minimize residential and other expropriation.

Around km 50, the route will enter a broad curve which will lead it to Mirabel Airport; that curve has a 4000 m radius allowing a maximum speed of 300 km/h.

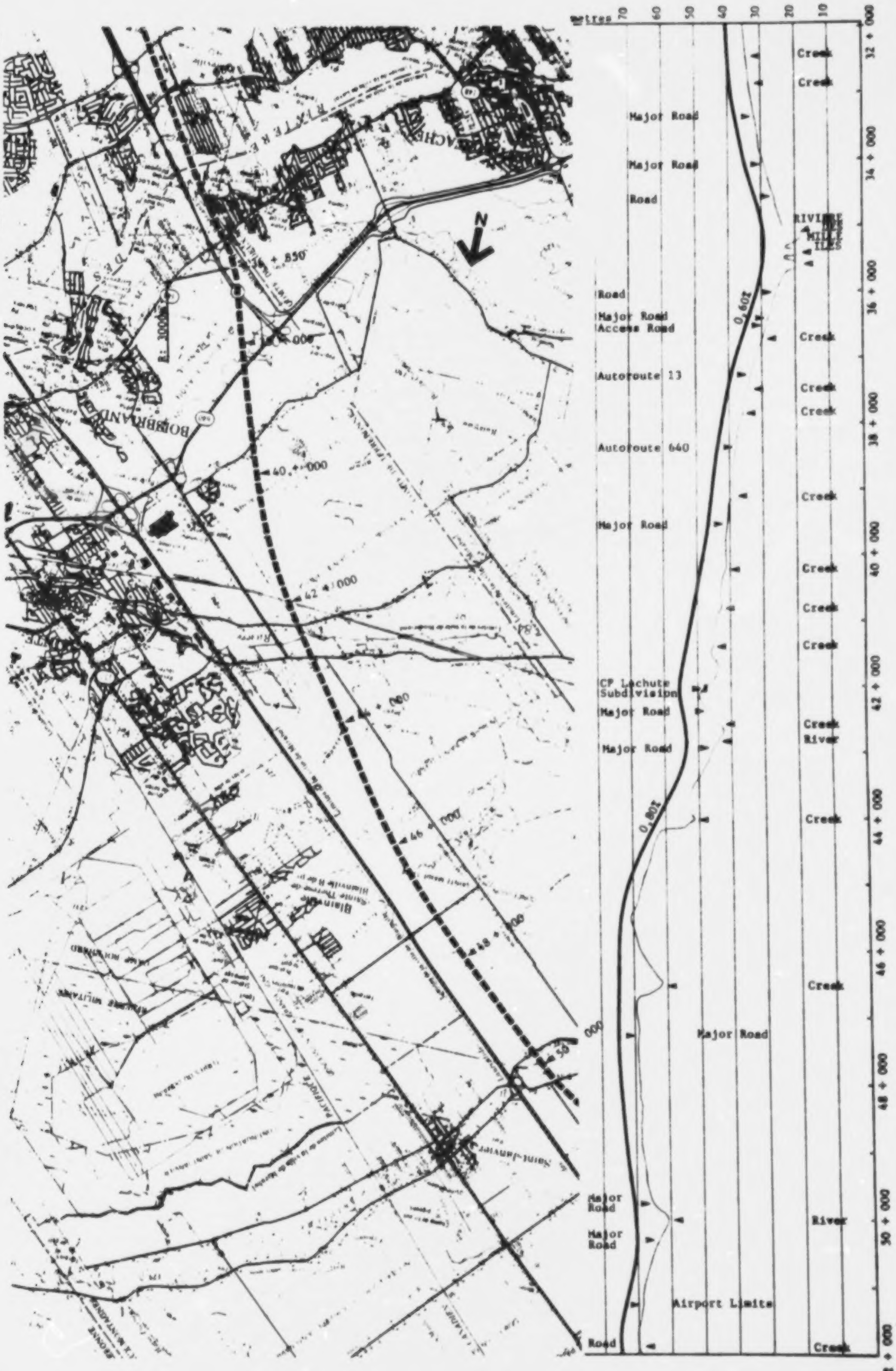
In this area, the Maglev guideway passes over one railroad (CP Subdivision Lachute), three power transmission corridors, and two limited-access expressways. In addition, Maglev crosses three suburban arterials, as well as five country roads, all of which are important, due to their alignment, location, or function, more than to the volume of traffic that they carry.

Due to a favorable alignment, only eighteen houses will have to be expropriated: ten, south of Autoroute 640; eight, north of it. Between km 33 and km 36 (approximately) the route passes close to residential areas and some form of noise barrier might be required.

The major part of "this section crosses a mixture of clay, sand and till deposits, interbedded and of undetermined depths. The mixture of consolidation strengths among these deposits, particularly the till, means that the choice of end bearing or friction piles will be an individual one for each colomn site" (1, p. 80).

Riviere des Mille Iles will be crossed using standard-span structures with a total length of 550 m.

FIGURE C-4 LAVAL-MIRABEL AREA



metres
70
60
50
40
30
20
10
32 + 000
34 + 000
36 + 000
38 + 000
40 + 000
42 + 000
44 + 000
46 + 000
48 + 000
50 + 000
Creek
Creek
Major Road
Major Road
Road
RIVIERE DES MILLE ILES
Road
Major Road
Access Road
Creek
Autoroute 13
Creek
Creek
Autoroute 640
Creek
Major Road
Creek
Creek
Creek
CP Lachute Subdivision
Major Road
Creek
River
Major Road
Creek
Creek
Major Road
Major Road
River
Major Road
Airport Limits
Road
Creek
0.60%
0.80%
+ 850
000
40 + 000
42 + 000
+ 000
46 + 000
48 + 000
50 000
N
BOISBRIAND
Blainville

C.4 Mirabel Airport Area (Figure C-5)

The Maglev alignment starts, in this area, around km 32, with a 4000 m curve to reach and follow the Airport Spine Road, combined with a downgrade to reach the terminal building at the level at which provision has been made for the construction of a train station. Right after leaving the station, the route turns to the right sharply and climbs back to 5 m above ground, following the spine Road. The aligment is shown in Figure C-5a.

The Maglev route crosses two landing trajectories of Mirabel Airport: Runway 24 (at 1300 m from the threshold) and Runway 11 (at 2300 m from the threshold). The maximum permissible elevation near such runways is 14 m for each 1000 m away from the threshold. As the guideway is never closer than 800 m from any runway, and is built 5 m above or below ground level in this area, no special corrective action is necessary to avoid interference with the landing paths.

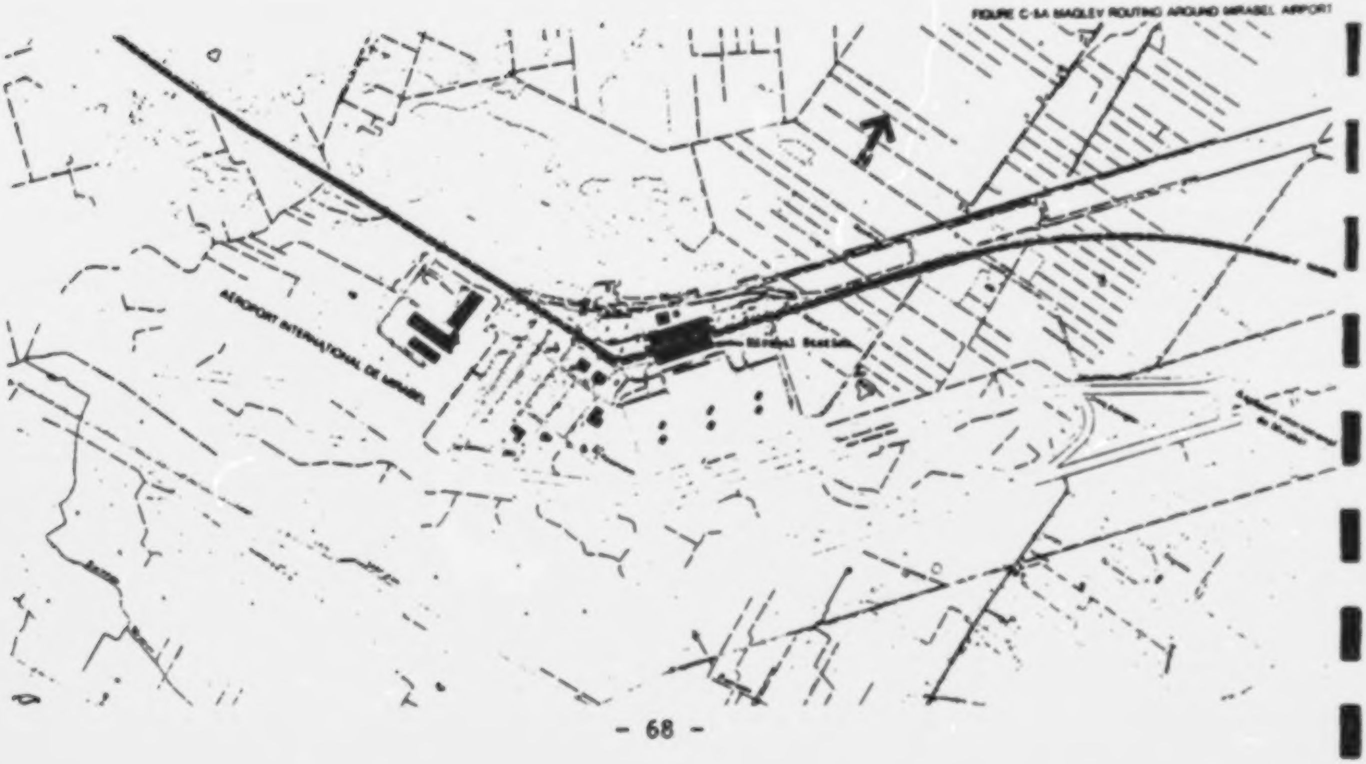
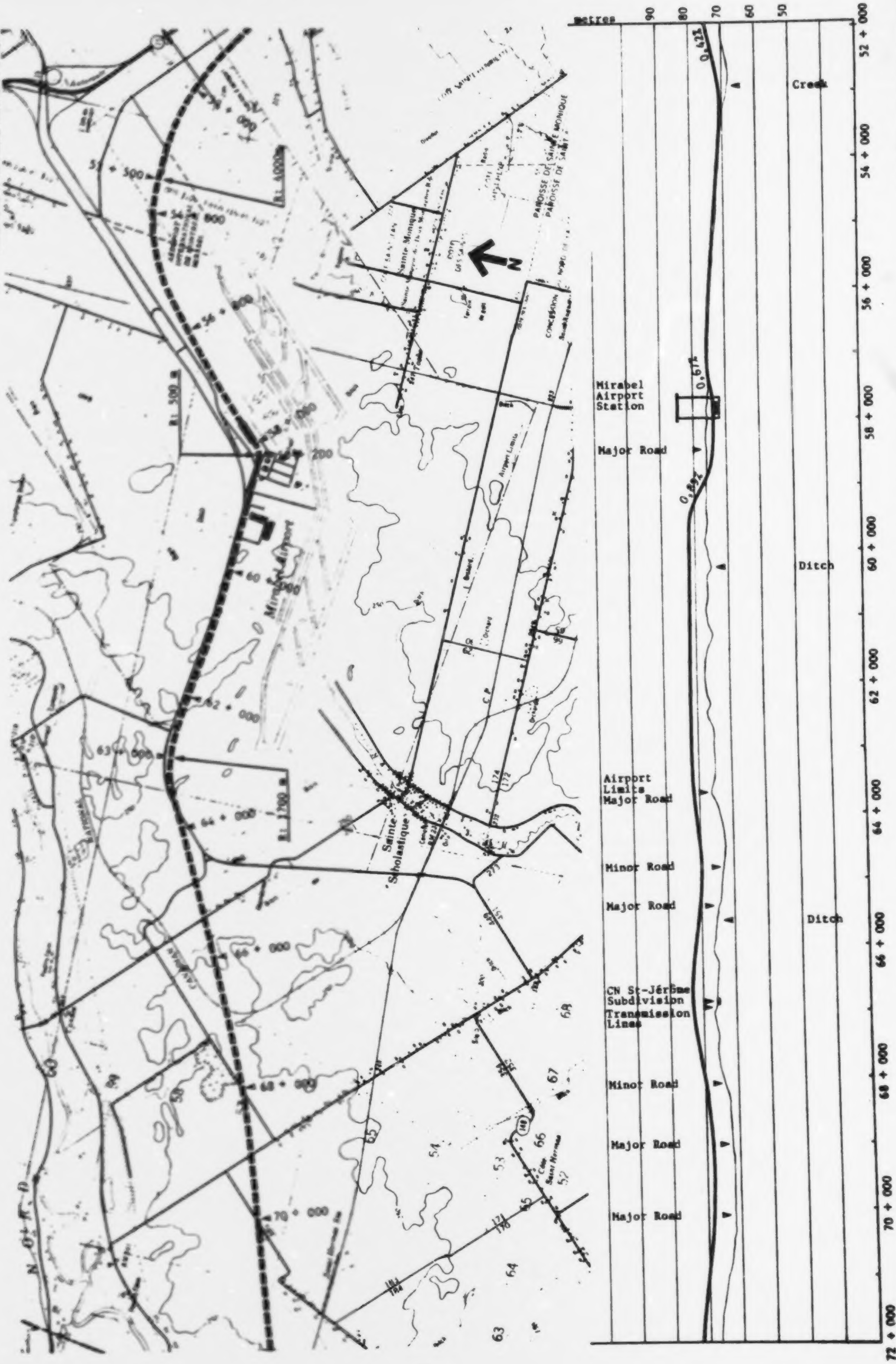


FIGURE C-5A MAGLEV ROUTING AROUND MIRABEL AIRPORT

FIGURE C-5 MIRABEL AIRPORT AREA


53 + 500
54 + 800
56 + 000
58 + 000
58 + 200
60 + 000
62 + 000
63 + 000
64 + 000
66 + 000
68 + 000
70 + 000
Rl 1000 m
Rl 500 m
Rl 1200 m
Mirabel Airport
Sainte Monique
Sainte Scholastique
Airport Limits
PAROISSE DE SAINTE MONIQUE
N
metres
90
80
70
60
50
0,422
0,672
0,892
Creek
Mirabel Airport Station
Major Road
Ditch
Airport Limits Major Road
Minor Road
Major Road
Ditch
CN St-Jérôme Subdivision
Transmission Lines
Minor Road
Major Road
Major Road
52 + 000
54 + 000
56 + 000
58 + 000
60 + 000
62 + 000
64 + 000
66 + 000
68 + 000
70 + 000
72 + 000

C.5 Lachute Area (Figure C-6)

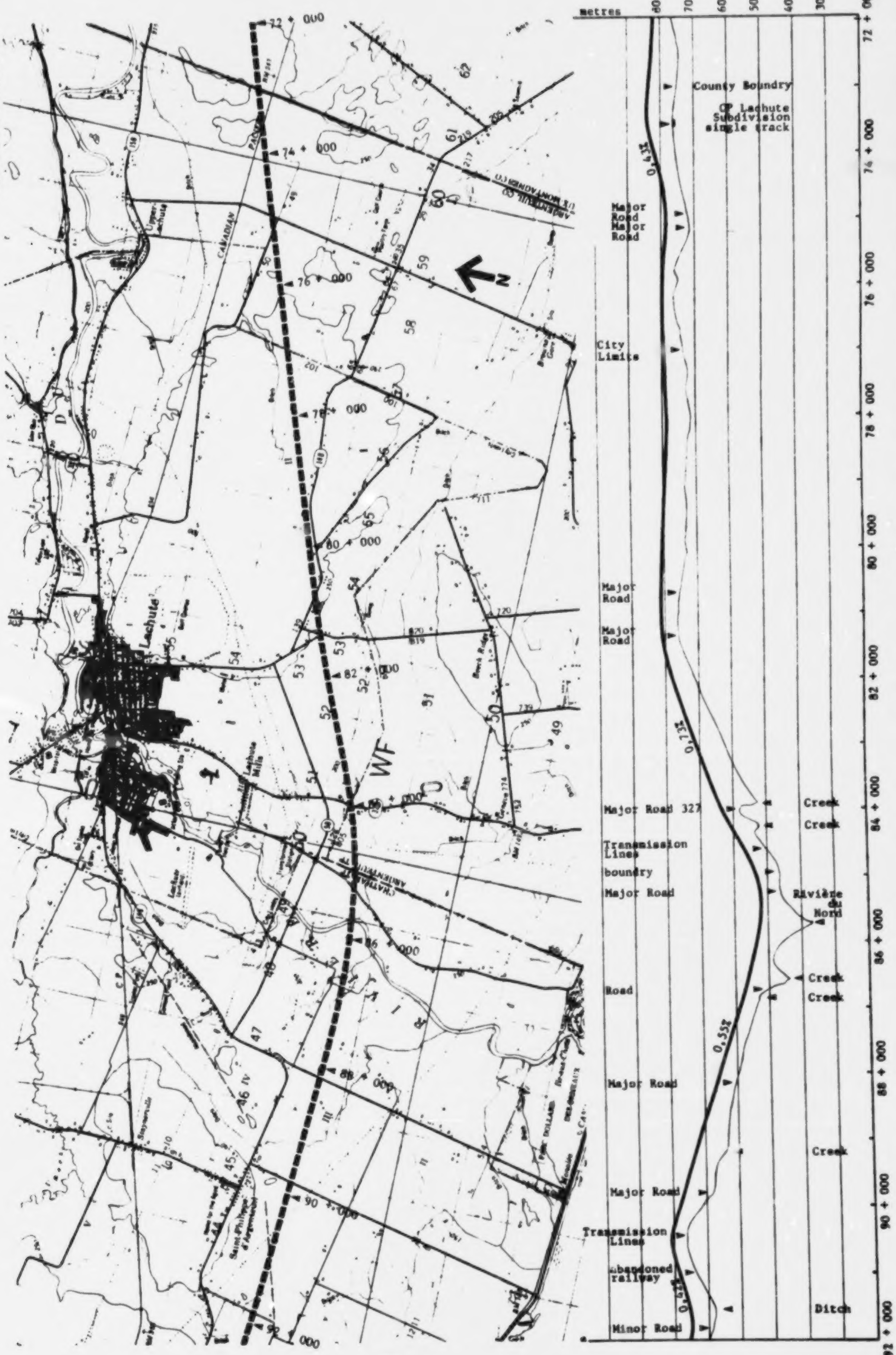
In this area, the Maglev route is straight for 10 km in a southwesterly direction. It then starts a gentle curve so that, at km 92, it points slightly north of West. The route passes approximately 3 km South of Lachute and 1 km south of Saint-Philippe-d'Argenteuil.

In all of this area, the guideway is built on an elevated structure approximately 5 m above ground level. The actual height will vary somewhat with the terrain, as the guideway does not follow its contour closely.

From km 72 to km 92 in the Lachute area, the Maglev guideway passes over CP Subdivision Lachute, Rivière du Nord (to be crossed by a structure with a standard span of 72 m), Highways 148 and 327, as well as eight country roads and two power transmission lines. The construction of an elevated structure precludes the need for culverts for small rivers and streams or in place of farm crossings.

Not more than five residences would need to be expropriated.

FIGURE C-6 LACHUTE AREA


72 + 000
74 + 000
76 + 000
78 + 000
80 + 000
82 + 000
84 + 000
86 + 000
88 + 000
90 + 000
92 + 000
Lachute
Upper Lachute
Lachute Mills
Saint-Philippe d'Argenteuil
CANADIAN PACIFIC
WF
N
metres
80
70
60
50
40
30
County Boundry
CP Lachute Subdivision single track
0.43%
Major Road
Major Road
City Limits
Major Road
Major Road
0.73%
Major Road 327
Creek
Creek
Transmission Lines
boundry
Major Road
Rivière du Nord
Road
Creek
Creek
0.55%
Major Road
Creek
Major Road
Transmission Lines
Abandoned railway
0.41%
Ditch
Minor Road

C.6 Hawkesbury Area (Figure C-7)

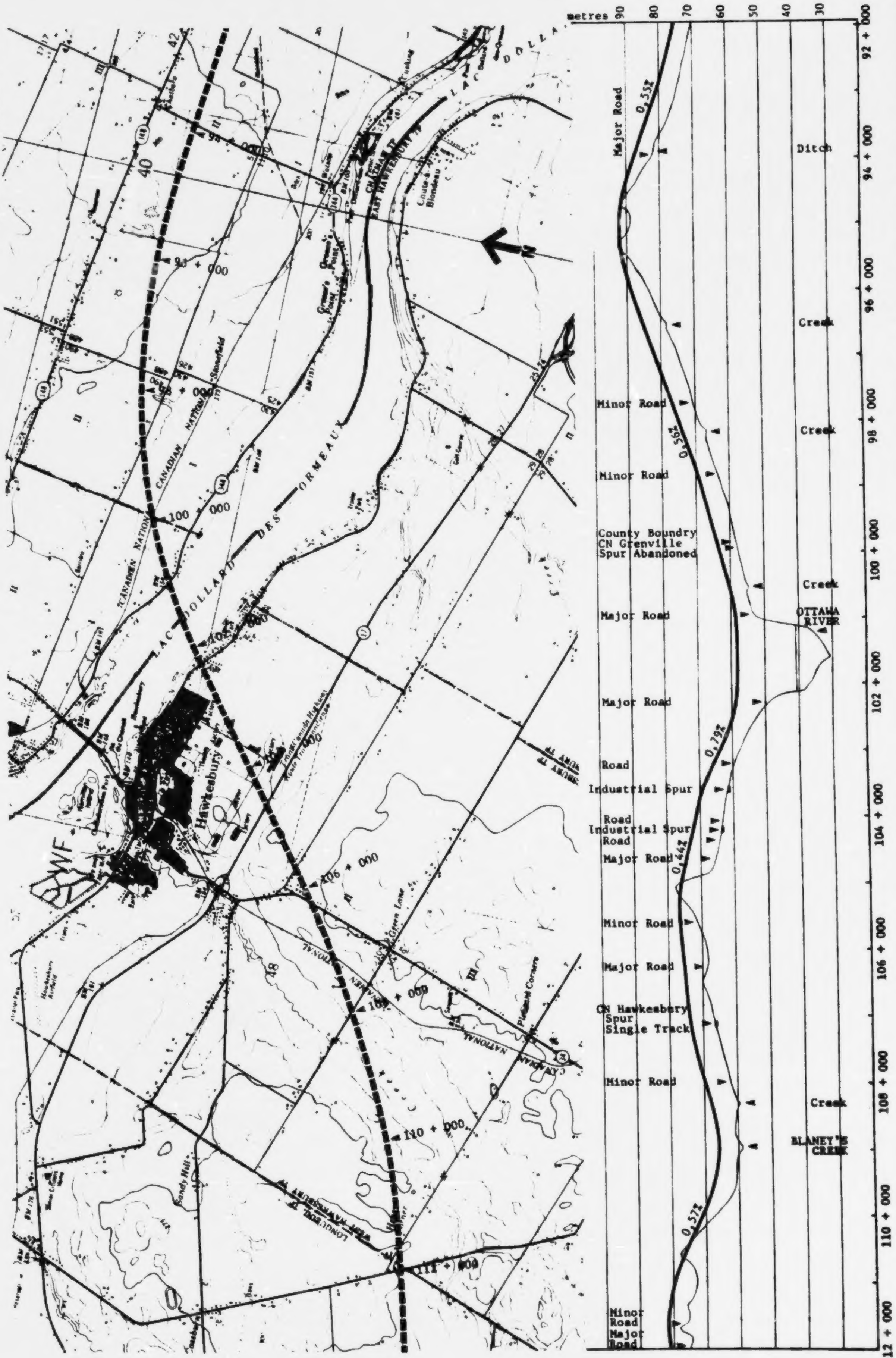
The route enters this area at km 95 near an area of Chatham Township known as Chatboro. Around km 101, the route reaches the shore of the Ottawa River, having swept through a gentle curve over three country roads, CN Grenville Spur, and Highway 344.

Landing in Ontario on the right shore of the Ottawa river at km 102, the alignment adopts a southwesterly heading which it will keep, with few small deviations, until it reaches Ottawa. At the western edge of this area, the route is at km 113+200 having passed over the following features since reaching Ontario: a major road along the shore, an industrial park with railway sidings, Highway 17 (Trans Canada Highway), CN Hawkesbury Spur, and five country roads.

> The alignment adopted in this area is that selected by CIGGT. "The Ottawa River crossing is the major structure on the entire routing, with a bank-to-bank distance of 1100 meters. The present site for Ottawa River crossing represents something of a compromise between minimum crossing length and optimum river depth and bank conditions. Some apparently better crossing locations, in terms of both river width and ... alignment, in the Chute-à-Blondeau area, ceased to be so attractive when "holes" at 93 m ... and 64 m ... souding depths were found to exist in the channel with what had been mapped as an inferred geological fault adjacent to them".
>
> "The Hawkesbury crossing site has problems only on the south bank, where the routeway emerges from the industrial park, through the eastern edge of town, to the river bank. These outskirts, however, look rather run down. On the north ern bank, the alignment is able to take advantage of a clear space between a few rather large, old summer homes to reach the Ottawa River" (1, p. 80)

The alignment selected implies demolition or relocation of fourteen houses, with little if any other environmental impact.

FIGURE C-7 HAWKESBURY AREA



metres
90
80
70
60
50
40
30
92 + 000
94 + 000
96 + 000
98 + 000
100 + 000
102 + 000
104 + 000
106 + 000
108 + 000
110 + 000
112 + 000
Major Road
0.55%
Ditch
Creek
Minor Road
0.56%
Creek
Minor Road
County Boundry
CN Grenville
Spur Abandoned
Creek
Major Road
OTTAWA
RIVER
Major Road
0.79%
Road
Industrial Spur
Road
Industrial Spur
Road
Major Road
0.44%
Minor Road
Major Road
CN Hawkesbury
Spur
Single Track
Minor Road
Creek
BLANEY'S
CREEK
0.57%
Minor
Road
Major
Road
LAC DOLLARD DES ORMEAUX
CANADIAN NATIONAL
Hawkesbury
Sandy Hill
Green Lane
N
94 + 000
95 + 000
98 + 000
100 000
102 + 000
106 + 000
108 + 000
110 + 000
111 + 000
40
42
17

C.7 Alfred Bog Area (Figure C-8)

Throughout this area from km 113+200 to km 133+300, the alignment is straight, and heads in a southwesterly direction. The route passes to the south of Caledonia Springs, barely touching the northern edge of Alfred Bog. The guideway is built 5 m above ground level.

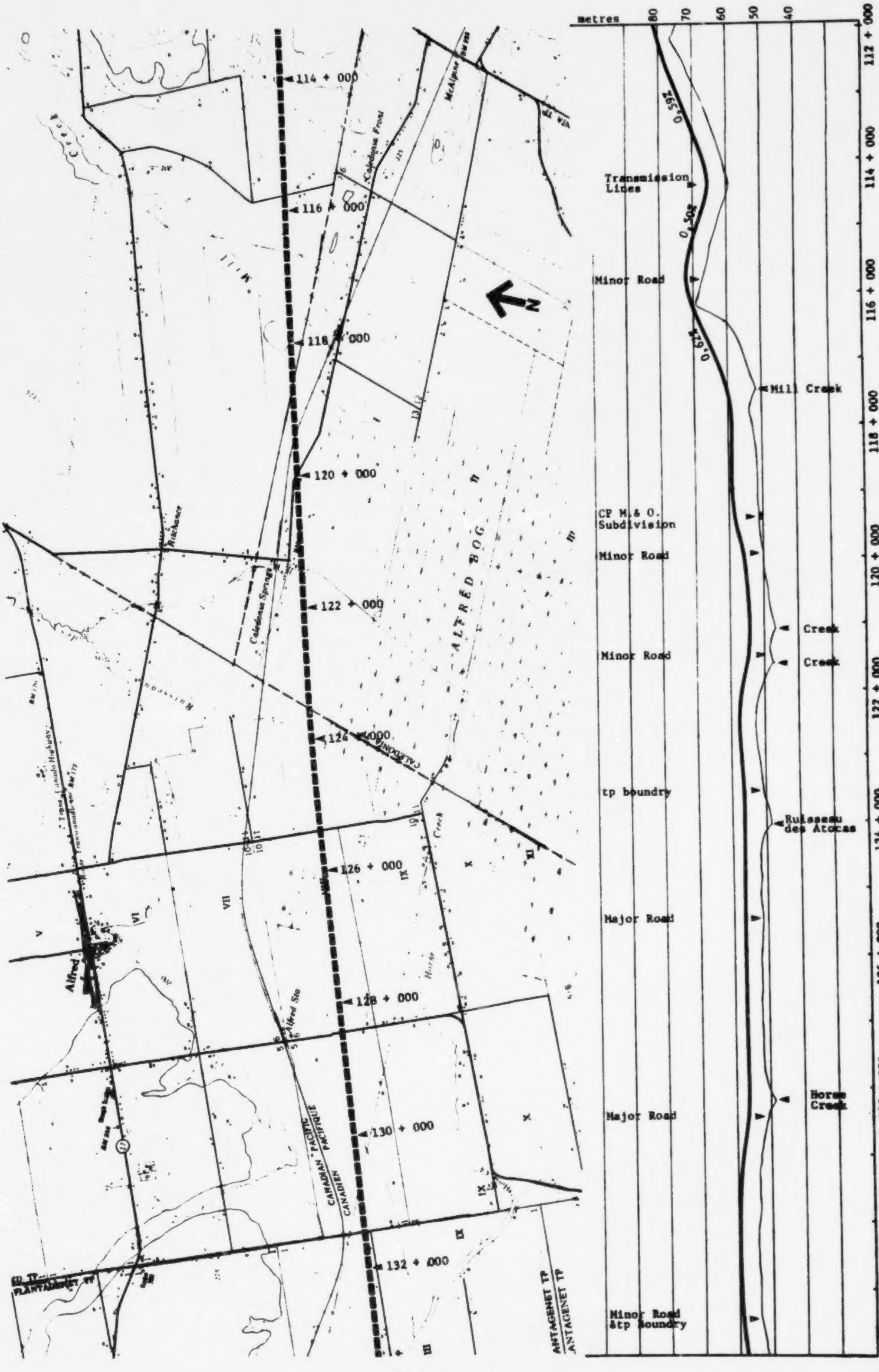
In addition to CP Subdivision M.&O., the guideway passes over five country roads and several drainage and irrigation ditches; it also crosses one power transmission line. A minimal amount of expropriation will be needed, but sound protection could be required near Caledonia Springs.

Although no special structure is required in this area, serious problems with soil conditions are probable. Pier foundations will be a problem, mainly near Alfred Bog, where the ground consists of soft peat, sometimes quite deep.

> "The provision of firm column foundations becomes a major problem, magnified in importance by the critical requirements for accuracy in the alignment, both vertically and horizontally, of the guideway beams, and the required permanency of this accurate alignment.
>
> Piled foundations are undoubtedly the best solution, but whether end-bearing or friction depends entirely on the conditions found at each site. The moranic clay and sand deposits in this region are notorious for their unpredictability. Most of the sand has been deposited on clay, which in turn often lies on more sand or gravel deposits, rather than directly on bedrock. The depth of overburden to bedrock can also vary widely within even a small area, the deepest recorded being over 61 m.
>
> The irregular nature of the bedrock and the nature of the clay deposits themselves result in some strange behaviour on the part of the overburden. In particular, a homogeneous deposit may decrease, rather than increase, in strength with depth from surface, if the bedrock surface drops off abruptly. On the other hand, compositional variations at a relatively constant depth can also produce problems of this nature. The clays in this area are predominently marine in origin, but there are on-lap and off-lap sequences with non-marine clays over beach deposits along the fringes of the old Champlain Sea basin." (1, p. 79)

From this area to Ottawa, soil conditions will continue being bad.

FIGURE C-8 ALFRED BOG AREA


114 + 000
116 + 000
118 + 000
120 + 000
122 + 000
124 + 000
126 + 000
128 + 000
130 + 000
132 + 000
Caledonia Front
McAlpine
Caledonia Springs
Richance
ALFRED BOG
CALEDONIA
Alfred
Alfred Sta
CANADIAN PACIFIC
CANADIEN PACIFIQUE
Trans-Canada Highway
Horse Creek
Creek
Mill
N
V
VI
VII
IX
X
XI
III
PLANTAGENET TP
ANTAGENET TP
metres
80
70
60
50
40
0.592
0.508
0.424
Transmission Lines
Minor Road
Mill Creek
CP M.& O. Subdivision
Minor Road
Creek
Minor Road
Creek
tp boundry
Ruisseau des Atocas
Major Road
Major Road
Horse Creek
Minor Road &tp Boundry
112 + 000
114 + 000
116 + 000
118 + 000
120 + 000
122 + 000
124 + 000
126 + 000
128 + 000
130 + 000
132 + 000

C.8 Plantagenet Area (Figure C-9)

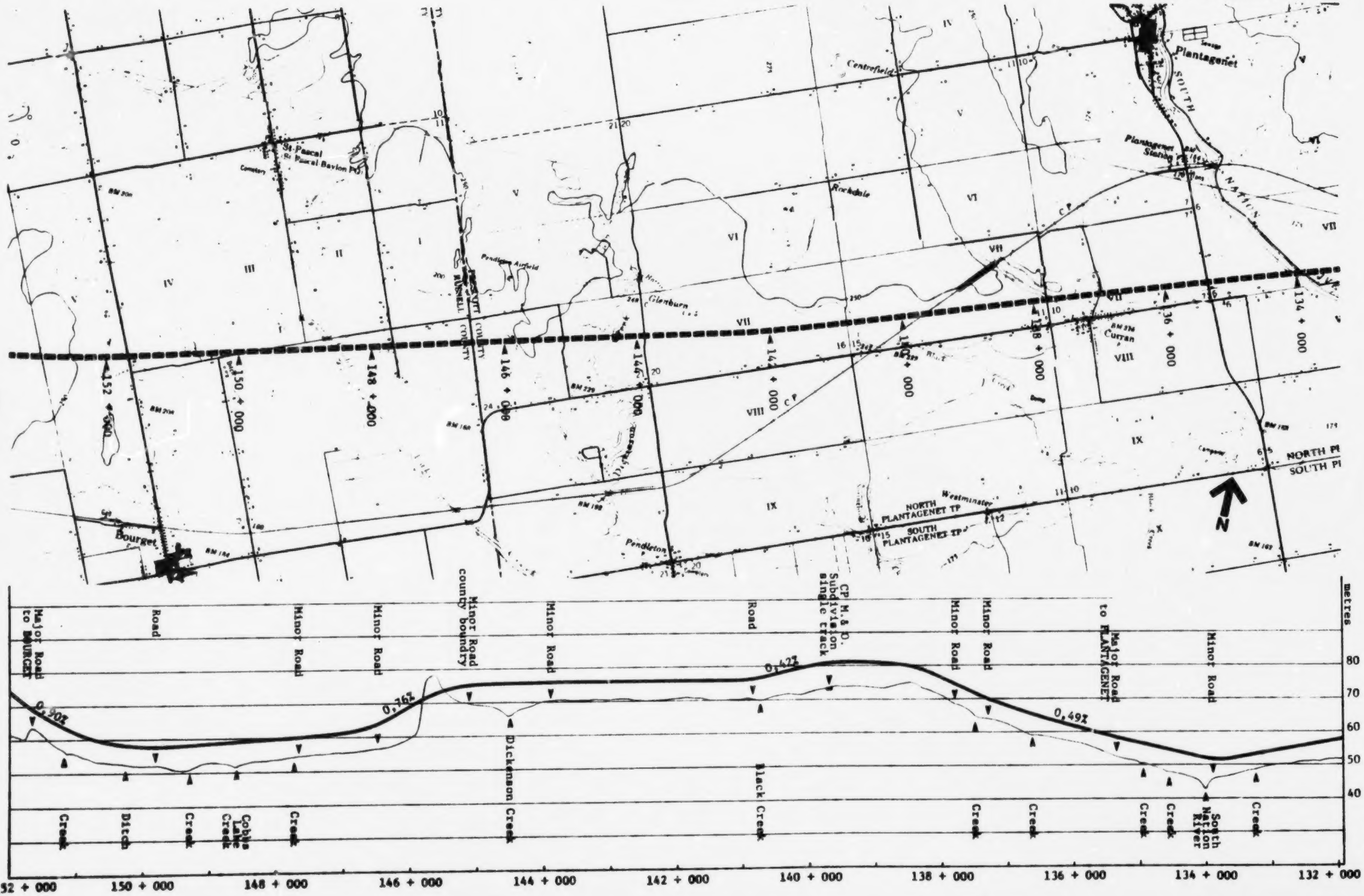
In this area, the alignment is practically straight from km 133+350 to km 153+450. The route successively crosses South Nation River, passes north of Curran, south of Pendleton Airport, slowly changing direction, slightly toward the West.

One special structure will be required in this area: to cross South Nation River at km 134. A 150 m span will be required to bridge the river, which has "a rather deeply incised channel cut into the limestone bedrock" (1, p.79)

In this area, the Maglev route passes over ten country roads, as well as CP Subdivision M.&O., where a clearance of 7 m above rail is required. Otherwise standard spans should suffice, except perhaps when crossing Cobbs Lake Creek at km 148+600, where a longer span could be required.

Expropriations are required at km 137, km 145+900, km 150+400, and km 151+700, for a total of five houses, presumably single-family devellings.

FIGURE C-9 PLANTAGENET AREA

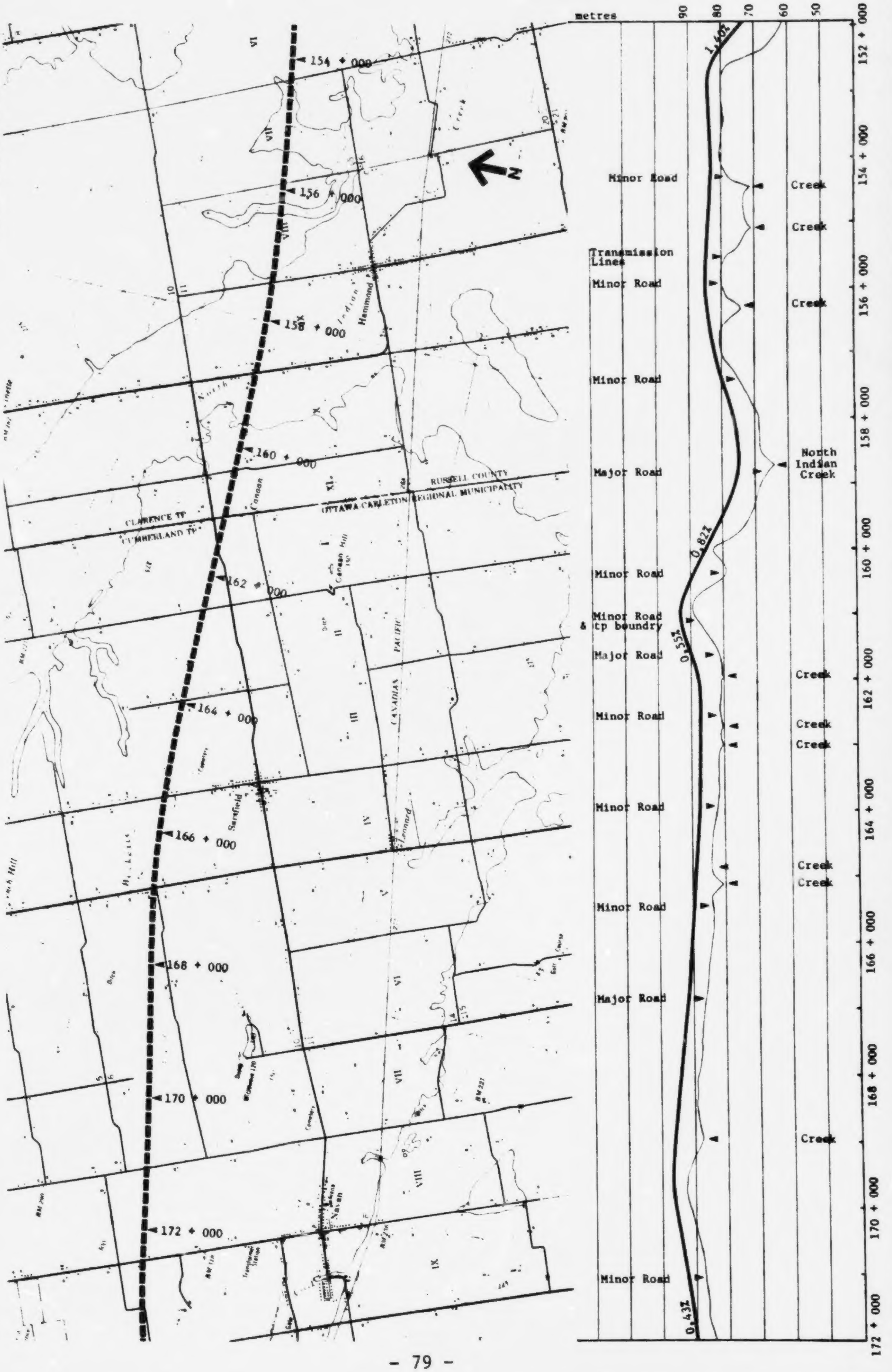

Plantagenet
SOUTH NATION
Plantagenet Station
Centrefield
Rockdale
Curran
Glenburn
Pendleton Airfield
Pendleton
St-Pascal
St-Pascal Baylon P.O.
Bourget
Dickenson
Westminster
NORTH PLANTAGENET TP
SOUTH PLANTAGENET TP
PRESCOTT COUNTY
RUSSELL COUNTY
N
134 + 000
136 + 000
138 + 000
140 + 000
142 + 000
144 + 000
146 + 000
148 + 000
150 + 000
152 + 000
metres
80
70
60
50
40
Major Road to BOURGET
Road
Minor Road
Minor Road
Minor Road county boundry
Minor Road
Road
CP M.& O. Subdivision single track
Minor Road
Minor Road
Major Road to PLANTAGENET
Minor Road
0,90%
0,76%
0,42%
0,49%
Creek
Ditch
Creek
Cobbs Lake Creek
Creek
Dickenson Creek
Black Creek
Creek
Creek
Creek
Creek
South Nation River
Creek
152 + 000
150 + 000
148 + 000
146 + 000
144 + 000
142 + 000
140 + 000
138 + 000
136 + 000
134 + 000
132 + 000

C.9 Hammond to Navan Area (Figure C-10)

In this area the Maglev route heads due West along a straight alignment from km 153+450 to km 173+700. It runs through open fields, 2 to 3 km north of CP Subdivision M.&O.

The alignment crosses one power transmission line and fourteen country roads, as well as eight creeks. In this area, special structures would be required only if difficult foundation conditions are encountered. The alignment often runs close to residences, but demolition or relocation of only four houses seems to be required, at km 154+350 and at km 172+500.

FIGURE C-10 HAMMOND-NAVAN AREA


154 + 000
156 + 000
158 + 000
160 + 000
162 + 000
164 + 000
166 + 000
168 + 000
170 + 000
172 + 000
RUSSELL COUNTY
OTTAWA CARLETON REGIONAL MUNICIPALITY
CLARENCE TP
CUMBERLAND TP
CANADIAN PACIFIC
Hammond
Canaan
Sarsfield
Leonard
Navan
N
metres
90
80
70
60
50
1.40%
0.82%
0.55%
0.43%
Minor Road
Creek
Creek
Transmission Lines
Minor Road
Creek
Minor Road
Major Road
North Indian Creek
Minor Road
Minor Road & tp boundry
Major Road
Creek
Minor Road
Creek
Creek
Minor Road
Creek
Creek
Minor Road
Major Road
Creek
Minor Road
152 + 000
154 + 000
156 + 000
158 + 000
160 + 000
162 + 000
164 + 000
166 + 000
168 + 000
170 + 000
172 + 000

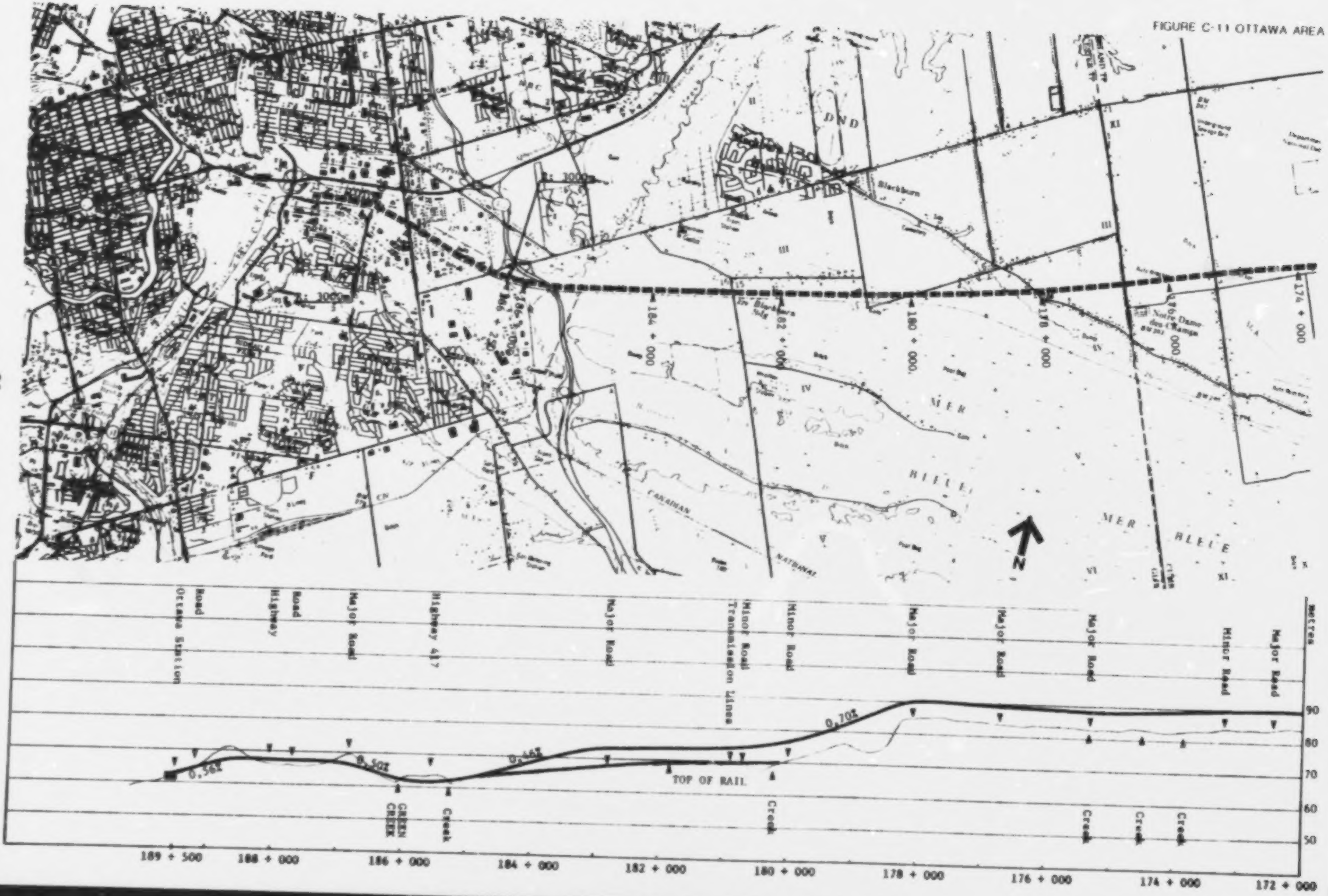
C.10 Ottawa Area (Figure C-11)

The route enters this final section at km 173+700, heading in a southwesterly direction. Running north of Notre-Dame-des-Champs, the Maglev route joins CP Subdivision M.&O. at km 182. The Maglev guideway is built on the north side of the right-of-way, all the way to the Ottawa terminal at km 189+500.

When approaching Ottawa, there are two successive reversed curves, both with a 3000 m radius: they are centered at km 186+250 and at km 188+650.

After passing Weir Road at km 182+750, the Maglev guideway progressively descends to ground level which is reached around km 185; the guideway remains on the north side of the rail right-of-way, as there is only one siding on that side. Overpasses carrying Highway 417 and Boulevard Saint-Laurent over the railway will have to be rebuilt. A new grade separation will have to be built at Innes Road. Partial expropriation of several light industries bordering the railway may be necessary depending on whether the existing and future tracks as well as the maglev guideway can all be built within the right-of-way. Triole and Michael Streets will be turned into culs-de-sac.

FIGURE C-11 OTTAWA AREA


174 + 000
176 + 000
178 + 000
180 + 000.
182 + 000
184 + 000
186 + 000
186 + 250
Blackburn
DND
MER BLEUE
CANADIAN NATIONAL
N
metres
90
80
70
60
50
Major Road
Minor Road
Creek
Major Road
Major Road
Major Road
Minor Road
Creek
Minor Road
Transmission Lines
TOP OF RAIL
Major Road
Highway 417
Creek
GREEN CREEK
Major Road
Road
Highway
Road
Ottawa Station
0.70%
0.46%
0.50%
0.56%
172 + 000
174 + 000
176 + 000
178 + 000
180 + 000
182 + 000
184 + 000
186 + 000
188 + 000
189 + 500

Reference

1. Canadian Institute of Guided Ground Transport, "Alternatives to Air. a feasible concept for the Montreal-Ottawa-Toronto Corridor", Transportation Development Centre, Transport Canada, Montreal, 1980.

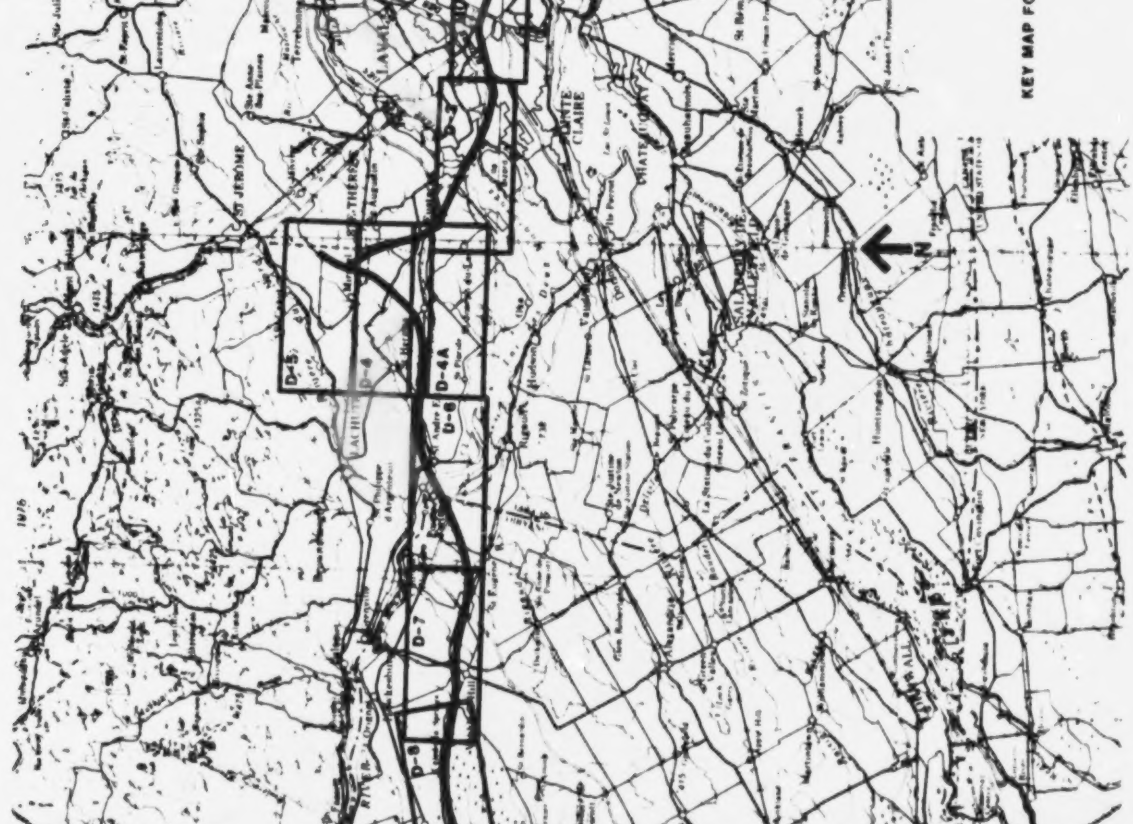
D. DESCRIPTION OF THE RAIL ROUTE

The objective of this appendix is to provide complementary information to the summary description of the Rail route that was presented in Section 4.6.

Like the preceding, this appendix consists of a series of topographical maps at the 1:50 000 scale, on which the alignment chosen is overlaid in plan; a short explanatory text accompanies each map and outlines the key features of the alignment in that section.

Each map is complemented by drawing showing the alignment in profile. As the terrain is fairly level between Montreal and Ottawa, an exaggerated vertical scale of 1:1000 has been chosen to better illustrate the vertical variations of the terrain and the alignment.

The Rail Key Map (figure D-1) consists of a 1:500 000 topographical map showing the from Montreal to Ottawa via Mirabel. The alignment in plan is overlaid on that base map. Also, individual maps at the 1:50 000, which are described in the following sections, are shown on the key map.


D-2
D-4
D-4A
D-5
D-6
D-7
D-8
D-10
MONTREAL
LAVAL
ST JEROME
LACHUTE
HULL
N

KEY MAP FOR RAIL ROUTE

FIGURE D-1

D.1 Montreal Area (Figure D-2)

Starting from the Montreal Terminal at Central Station, the route selected starts at Platforms 13 and 14 and follows the CN right-of-way towards Deux-Montagnes though the tunnel and the cities of Mount Royal, Montreal, Saint-Laurent, Pierrefonds, Roxboro, Laval and Deux-Montagnes.

At km 0+650, shortly after leaving Central Station, the alignment turns left in a 1000 m radius curve, to reach a final heading slightly north of West. This heading is kept through most of the tunnel. In the tunnel, the Rail system (HSR) shares tracks with other railway services.

The tunnel ends at km 5+400, after crossing Jean-Talon Street. From this point, four tracks are laid in the right-of-way. The HSR uses two exclusive tracks located on the south side. The commuter services use two exclusive tracks built on the north side of the right-of-way; commuter stations have central platforms built between these two tracks; these platforms are accessible exclusively from an overhead mezzanine. Wherever industrial freight service is required, one or two outside tracks are built in the right-of-way.

All the way to Deux-Montagnes, the Rail route is aligned on the south side of the right-of-way. The first noteable curve in that part of the route is found near Cartierville; it is centered at km 10+200; its 1200 m radius allows a safe speed of 164 km/h.

Before reaching that curve, the alignment passes under Graham and Laird Boulevards (km 6+400). It then crosses Jasper Lazard Street* and runs under Metropolitain Boulevard at km 7+350. Two industrial sidings on the south side at km 7+600 and km 7+850 will be served by a new freight track. Eastern Junction will have to be rebuilt to eliminate level crossings with other tracks. From km 8+600 to Autoroute 13, a freight track is built on the south side of the right-of-way.

---

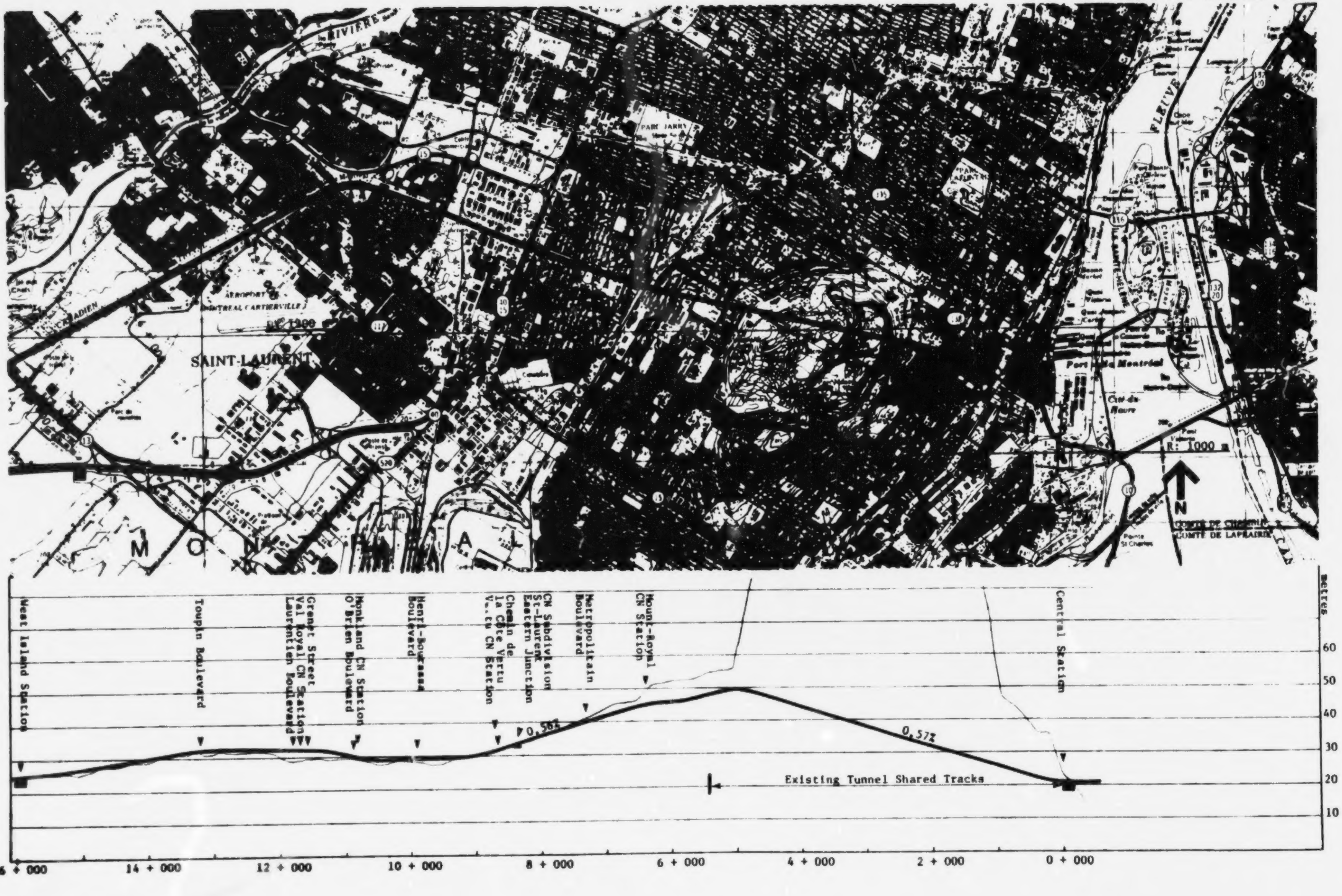
* this crossing, now temporarily closed, would have to be closed permanently

Construction of a new bridge would be needed to cross Chemin de la Côte-Vertu (near CN Vertu Station), but none is needed to cross Henri-Bourassa Boulevard as a bridge was built recently with capacity for future tracks. After the curve, the alignment heads Southwest. At km 10+900, it crosses O'Brien Boulevard (CN Monkland Station). Then the route passes over Grenet Street and Laurentien Boulevard in the area of the CN Val Royal Station around km 11+700. From km 11+300 to km 11+900 a sixth track will be built on the north side of the right-of-way to serve industries and connect to the Cartierville Spur.

The alignment enters CN Montfort Subdivision at km 11+950. The West Island Station, would be located at km 16 on the eastern side of Autoroute 13, near the edge of this map.

From km 8+700 to Autoroute 13, the following grade separation structures would have to be built or rebuilt: Chemin de la Côte-Vertu, O'Brien Boulevard (new structure), Grenet Street, Laurentian Boulevard, Toupin Boulevard (new structure).

FIGURE D-2 MONTREAL AREA


SAINT-LAURENT
PARC JARRY
Port de Montréal
R: 1000 m
N
COMTE DE LAPRAIRIE
MONTREAL
metres
60
50
40
30
20
10
Central Station
Mount-Royal CN Station
Metropolitain Boulevard
CN Subdivision St-Laurent Eastern Junction
Chemin de la Côte Vertu
Vertu CN Station
Henri-Bourassa Boulevard
Monkland CN Station
O'Brien Boulevard
Grenet Street
Val Royal CN Station
Laurentien Boulevard
Toupin Boulevard
West Island Station
0.57%
0.56%
Existing Tunnel Shared Tracks
16 + 000
14 + 000
12 + 000
10 + 000
8 + 000
6 + 000
4 + 000
2 + 000
0 + 000

D.2 Laval - Deux-Montagnes Area (Figure D-3)

The route passes under Autoroute 13 at km 16+100. In this map section, a total of eight noteable curves involving speed restrictions are found.

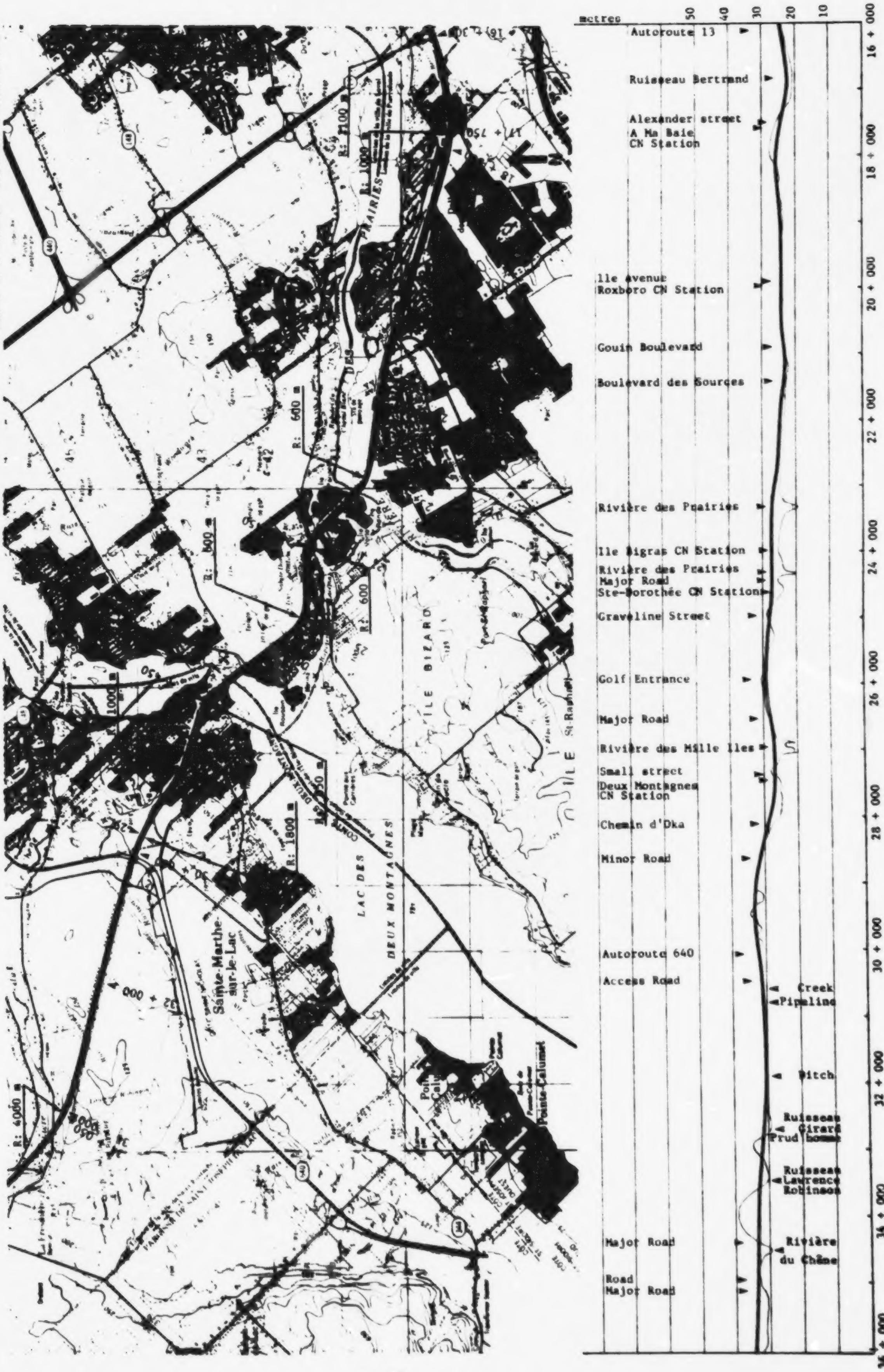
The first curve is centered around km 16+300; its radius of 2100 km allows a safe speed of 217 km/h. Running besides residential areas, the route crosses Ruisseau Bertrand at km 16+950, then Alexander Street near A-ma-Baie CN Station; this would have to be grade separated. The next curve is centered at km 17+750; its 1000 m radius allows a speed of 150 km/h.

The route crosses 11e avenue near CN Roxboro Station at km 19+950. Since it is impossible to close this street, the crossing will have to be grade-separated. Heading Northwest the alignment successively crosses Gouin Boulevard and Montée des Sources, a small street at that point; the crossing with the former road will be grade-separated and the latter will be closed and equipped with a pedestrian overpass.

The three most restrictive curves in the whole route for the rail technology are found in the next part of the route. All three have a radius of 600 m restricting the speed to 116 km/h. The first one is centered at km 23+100; it is followed by a tangent of 750 m. The second curve, in the opposite direction, is centered at km 24+450 and is followed by a tangent of 600 m. The last curve is centered around km 25+550 and brings the alignment back on a northwesterly heading.

Leaving the Montreal Island at km 23+350, the route crosses Rivière des Prairies toward Parizeau Island (shown as Bigras Island on the map) on a new 200 m long bridge. On that island, it crosses Chemin du Tour, passes CN Station Ile Bigras and crosses Rivière des Prairies for the second time, at km 24+450, on a new 120 m long bridge to Laval.

FIGURE D-3 LAVAL - DEUX-MONTAGNES AREA


metres
50
40
30
20
10
Autoroute 13
Ruisseau Bertrand
Alexander street
A Ma Baie CN Station
Ile avenue
Roxboro CN Station
Gouin Boulevard
Boulevard des Sources
Rivière des Prairies
Ile Bigras CN Station
Rivière des Prairies
Major Road
Ste-Dorothée CN Station
Graveline Street
Golf Entrance
Major Road
Rivière des Mille Iles
Small street
Deux Montagnes CN Station
Chemin d'Oka
Minor Road
Autoroute 640
Access Road
Creek
Pipeline
Ditch
Ruisseau Girard
Prud'homme
Ruisseau Laurence Robinson
Major Road
Rivière du Chêne
Road
Major Road
16 + 000
18 + 000
20 + 000
22 + 000
24 + 000
26 + 000
28 + 000
30 + 000
32 + 000
34 + 000
36 + 000
R: 1100 m
R: 1000 m
R: 600 m
R: 800 m
R: 600
R: 1000 m
R: 1800 m
R: 4000 m
ILE BIZARD
LAC DES DEUX MONTAGNES
Sainte-Marthe-sur-le-Lac
Pointe-Calumet

Before reaching CN Ste-Dorothée Station, two streets and one regional road (Rang du Bord de l'Eau) are crossed. Then, the route proceeds on the southwest fringe of the Laval-sur-le-Lac Golf Club. It the route successively crosses Les Cèdres Road (golf entry), Boulevard Les Erables (major road) and Rivière des Mille Iles. The river crossing requires a 120 m span to a small island and, from there, a 200 m bridge to Deux-Montagnes.

The route passes besides the last CN commuter station in Deux-Montagnes and crosses Boulevard du Lac (a small street) at km 27+400.

A curve to the left follows; centered at km 27+450, it has a radius of 850 m and allows a speed of 138 km/h. Next a reverse curve is centered at km 28+625; it has a 1000 m radius. A small tangent of 250 m follows before reaching the last noteable curve in this map section at km 29+450; its radius of 1800 m allows a safe speed of 201 km/h.

The route proceeds under Autoroute 640 (km 30+050). It then passes over one pipeline and four creeks and leaves the right-of-way at km 33+600. The route then passes over Chemin sud de la Petite Rivière, east of La Fresnière; a small bridge is needed to cross Rivière du Chêne. The route proceeds through the north side of the village beginning a turn toward Mirabel; two village streets are crossed and five houses must be expropriated.

To summarize, grade-separation structures will have to be built or rebuilt at the following crossings: Alexander Street (new), 11e avenue (new), Gouin Boulevard (new), Chemin du Tour (new), Rang du Bord de l'Eau (rebuilt), Les Cèdres Road (new), Boulevard les Erables (new), Boulevard du Lac (new), Chemin d'Oka (rebuilt), Henri-Dunant Street (new), Chemin sud de la Petite Rivière (new), and Montée Laurin in La Fresnière (new). All other crossings will be closed.

D.3 Two Mountain Area (Figure D-4)

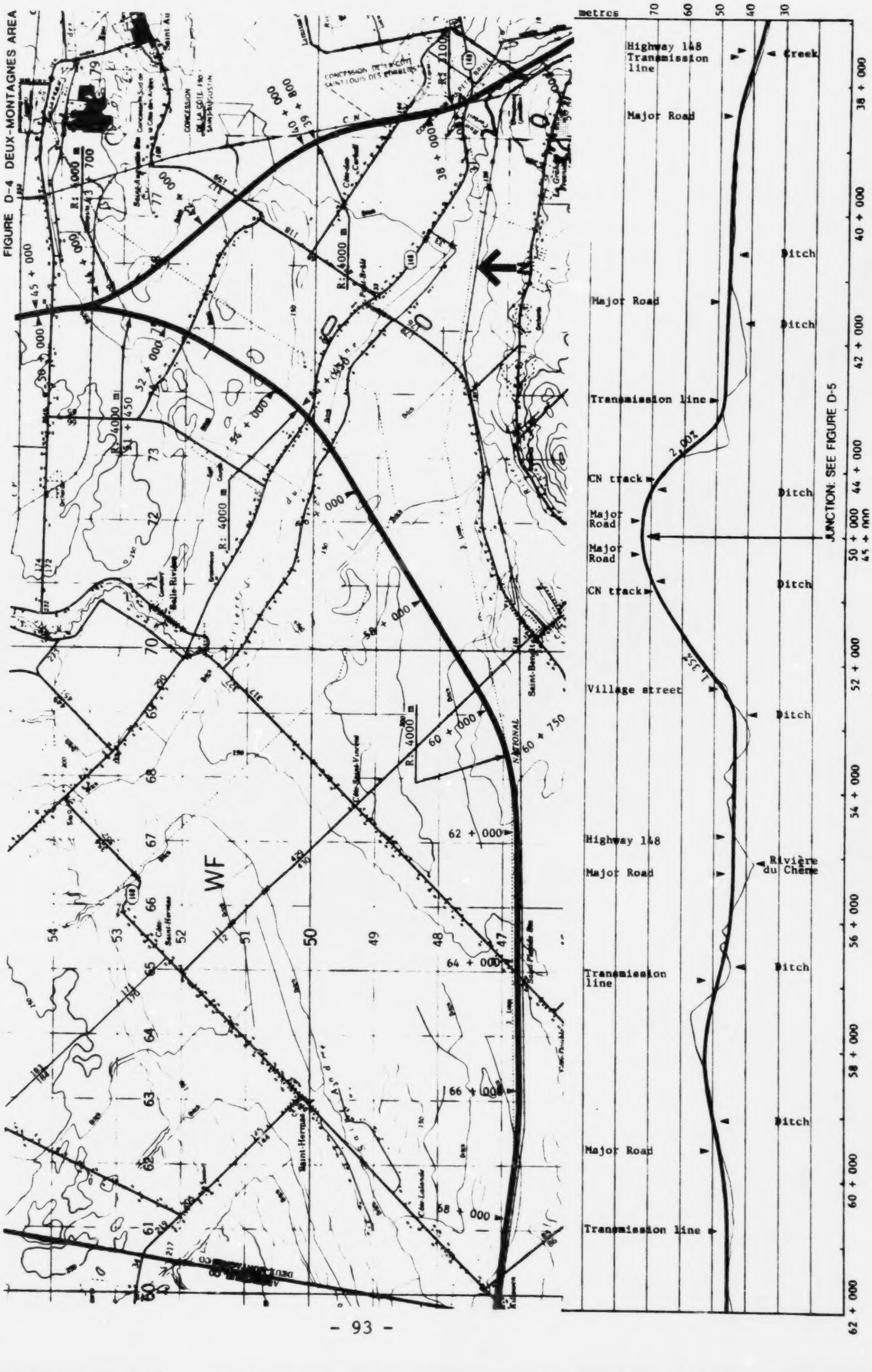
Leaving La Fresnière, the alignment proceeds towards CN Subdivision Montfort which it reaches north of Grenmont Junction. It then follows that CN right-of-way (passing west of the existing track), toward the North for approximatley 2,5 km. Before adopting a northbound alignment, there is a curve centered at km 37+600; its radius of 3100 m allows a safe speed of 261 km/h. In this area, the alignment crosses Rivière du Chêne twice: two new bridges are needed.

At km 37+400, the route crosses Highway 148: a grade separation structure would have to be built. Remaining in the CN right-of-way, the alignment also crosses one small creek and one major road, Côte-des-Corbeil, which will be closed. The route leaves the CN right-of-way at km 39+800. Another curve, with a 4000 m radius is centered at km 43+700: it provides the final alignment toward the airport. Between these curves, the route crosses two ditches, one major road that must be grade-separated and one power transmission line.

Proceeding northbound, the rail route, which is in cut, passes under CN Subdivision Montfort and CP Subdivision Lachute.

At km 45, 5 km south of the Air Terminal, the alignment from Montreal to Mirabel coincides with the alignment from Mirabel to Ottawa; the latter is described in Section D.5.

FIGURE D-4 DEUX-MONTAGNES AREA


45 + 000
R: 1000 m
43 + 700
40 + 800
39 + 000
38 + 000
R: 3100
R: 4000 m
41 + 450
52 + 000
54 + 000
56 + 000
R: 4000 m
58 + 000
60 + 000
R: 4000 m
60 + 750
62 + 000
64 + 000
66 + 000
68 + 000
CN
NATIONAL
WF
Belle-Rivière
Saint-Hermas
Saint-Benoît
Côte Saint-Vincent
CONCESSION DE LA CÔTE SAINT-LOUIS DES ERABLES
CONCESSION DE LA CÔTE SAINT-AUGUSTIN
metres
70
60
50
40
30
Highway 148
Transmission line
Creek
Major Road
Ditch
Major Road
Ditch
Transmission line
2.00%
CN track
Ditch
Major Road
Major Road
JUNCTION: SEE FIGURE D-5
CN track
Ditch
1.35%
Village street
Ditch
Highway 148
Rivière du Chêne
Major Road
Transmission line
Ditch
Ditch
Major Road
Transmission line
38 + 000
40 + 000
42 + 000
44 + 000
50 + 000
45 + 000
52 + 000
54 + 000
56 + 000
58 + 000
60 + 000
62 + 000

D.4 Mirabel Airport Station (Figure D-5)

The station will be built in the lower level of the existing air terminal building, which has been designed for such a possibility.

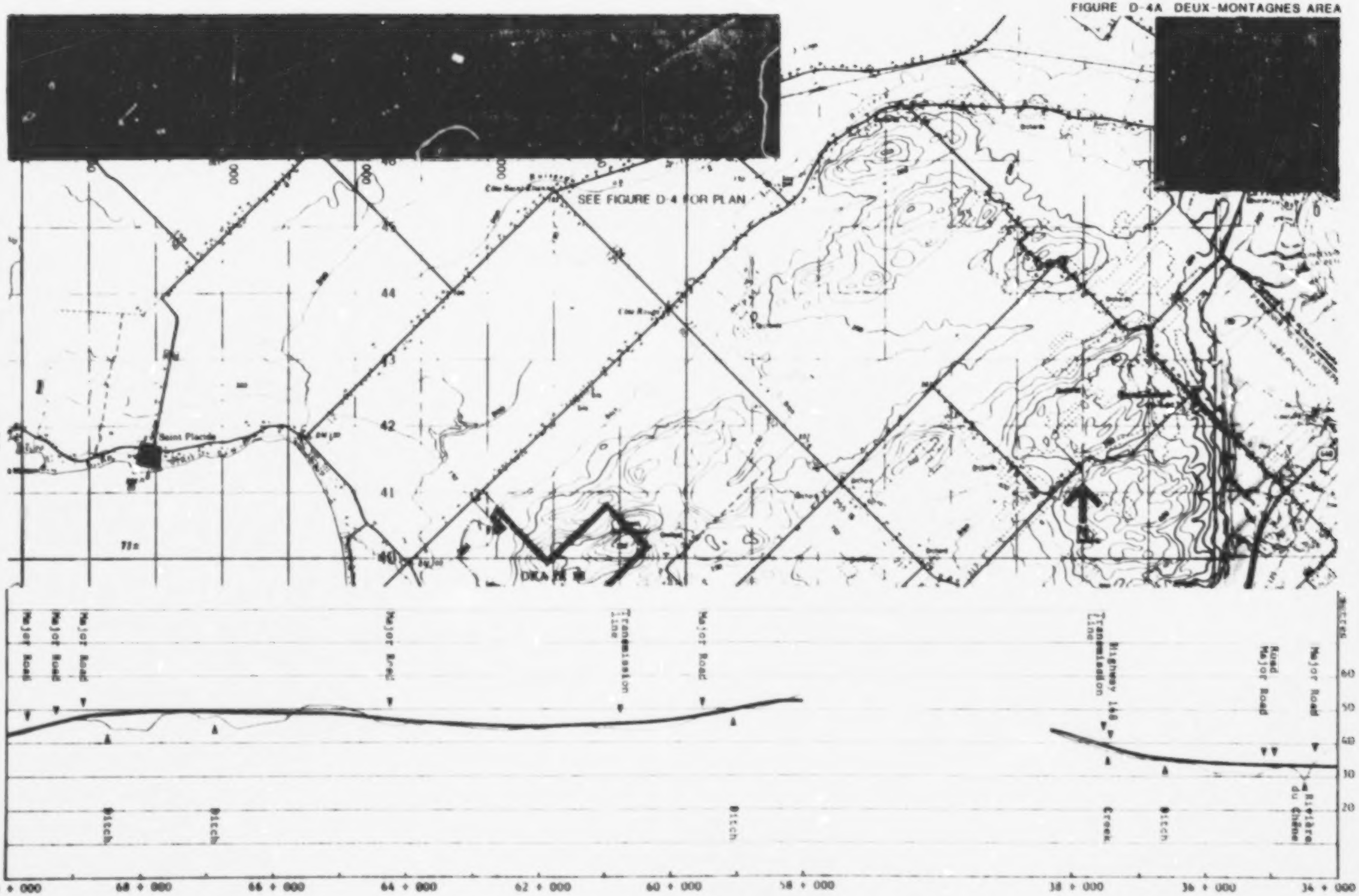
Access is from the South. The alignment will pass near the end of Runways 29 and cross two existing taxiways and several airport service roads. In addition, provision has to be made for airport expansion: future Runway 29L, parallel to existing Runway 29, as well as its taxiways.

Accordingly, starting at around km 45+400, the Rail route will progressively descend to such a level that the system will pass under future Runway 29L: it will be built in a cut at the appropriate level.

From km 48+300 to the air terminal building (km 50+000) a 1,7 km tunnel will be built to pass under the taxiways, service roads and airport service buildings. A similar tunnel will have to be built upon construction of Runway 29L and its taxiways.

Once the train has stopped at Mirabel Airport, it will reverse direction and proceed towards Ottawa. For 5 km, the return route follows the exact alignment used for access to Mirabel: from km 50+000 to km 45+000. At that point, the route towards Ottawa diverges from the route towards Montreal.

FIGURE D-4A DEUX-MONTAGNES AREA


SEE FIGURE D-4 FOR PLAN
44
43
42
41
40
metres
60
50
40
30
20
Major Road
Major Road
Major Road
Major Road
Transmission line
Major Road
Transmission Line
Highway 148
Road
Major Road
Major Road
Rivière du Chêne
Ditch
Ditch
Ditch
Creek
Ditch
70 + 000
68 + 000
66 + 000
64 + 000
62 + 000
60 + 000
58 + 000
38 + 000
36 + 000
34 + 000

D.5 Mirabel Airport to Saint-Placide (Figure D-4a)

From the junction point, the alignment heads southbound. Three 4000 m curves will slowly change this heading to West toward Ottawa. These curves are located at km 51+450, km 54+450 and km 60+750. After the last curve, the alignment joins the right-of-way of Grenville Spur in CN Subdivision Montfort.

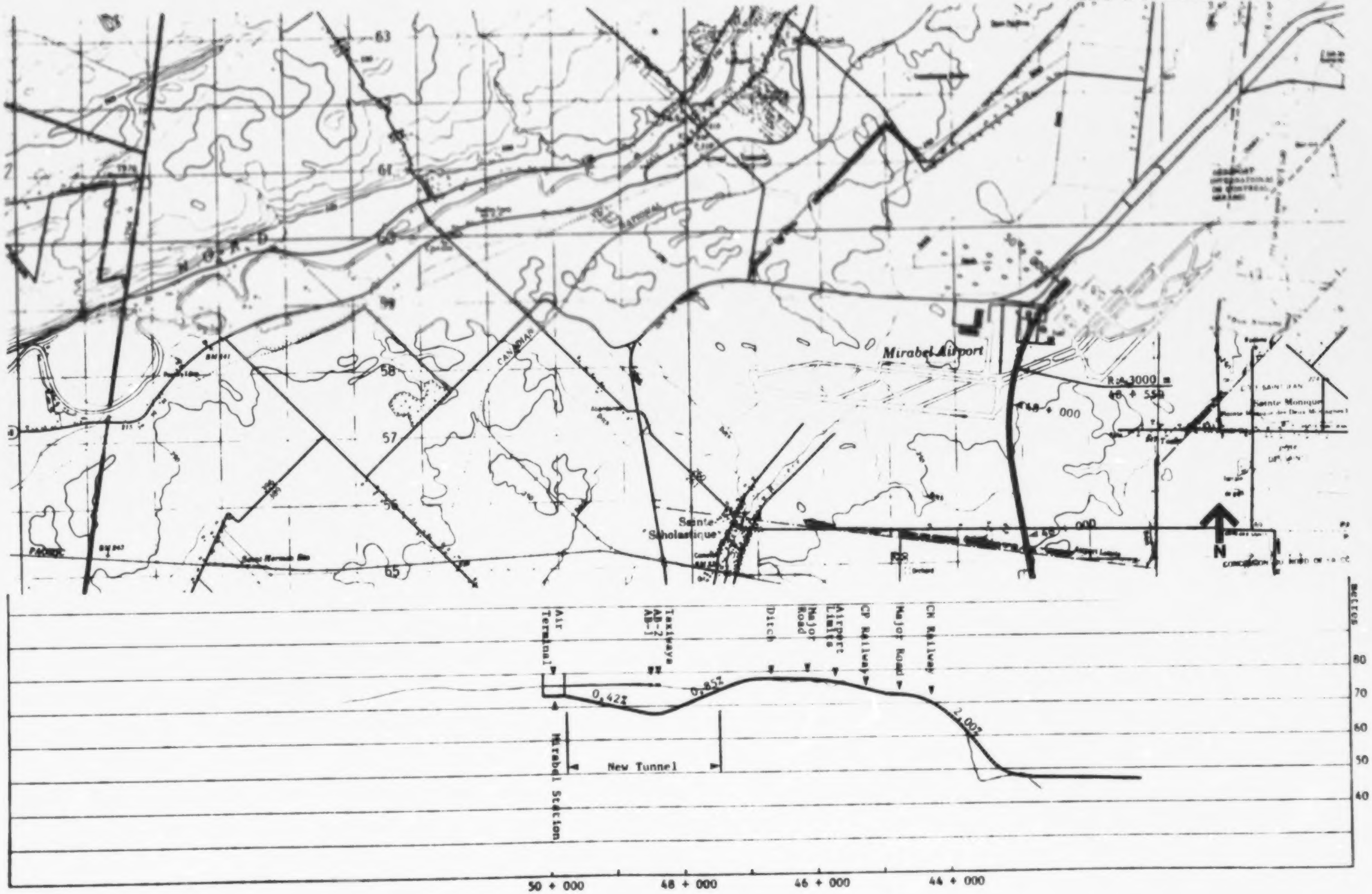
Before reaching that point, the route successively passes under Côte-des-Anges Road and CN Subdivision Montfort. Then it crosses a major road, one ditch, and Highway 148, where three expropriations are needed. Southwest of this road, the alignment crosses Rivière du Chêne, two other roads, two ditches and two power transmission lines.

Grade separations are needed for the crossing of Highway 148 and Côte-des-Anges Road. All other road crossings will be closed and some roads detoured.

From km 62, the route is aligned on the north side of the right-of-way of CN Grenville Spur, heading westbound. One major road is crossed at km 64+200 near CN Saint-Placide Station; that crossing will be grade-separated.

Before leaving this map section at km 69+400, two ditches and two major roads are crossed. The first road, from Saint-Placide to Kiloween, will be relocated south of the existing track for 0,5 km. The second road has to be grade-separated. A total of five expropriations are needed in this route section.

FIGURE D-5 MIRABEL AIRPORT STATION


Mirabel Airport
Sainte Scholastique
Sainte Monique
N
R=3000 m
48 + 550
48 + 000
NORD
CANADIAN
PACIFIC
63
61
60
58
57
56
65
metres
80
70
60
50
40
Air Terminal
Taxiways AB-2 AB-1
Ditch
Major Road
Airport Limits
CP Railway
Major Road
CN Railway
0,42%
0,85%
2,00%
Mirabel Station
New Tunnel
50 + 000
48 + 000
46 + 000
44 + 000

D.6 Ottawa River Crossing (Figure D-6)

After crossing two major roads around CN Station Lalande, the route leaves the CN right-of-way. The first road will be relocated north of the route and the second will be grade-separated. The chosen alignment allows for a greater speed than using the CN line and minimizes environmental impacts (including expropriations) near the Ottawa River.

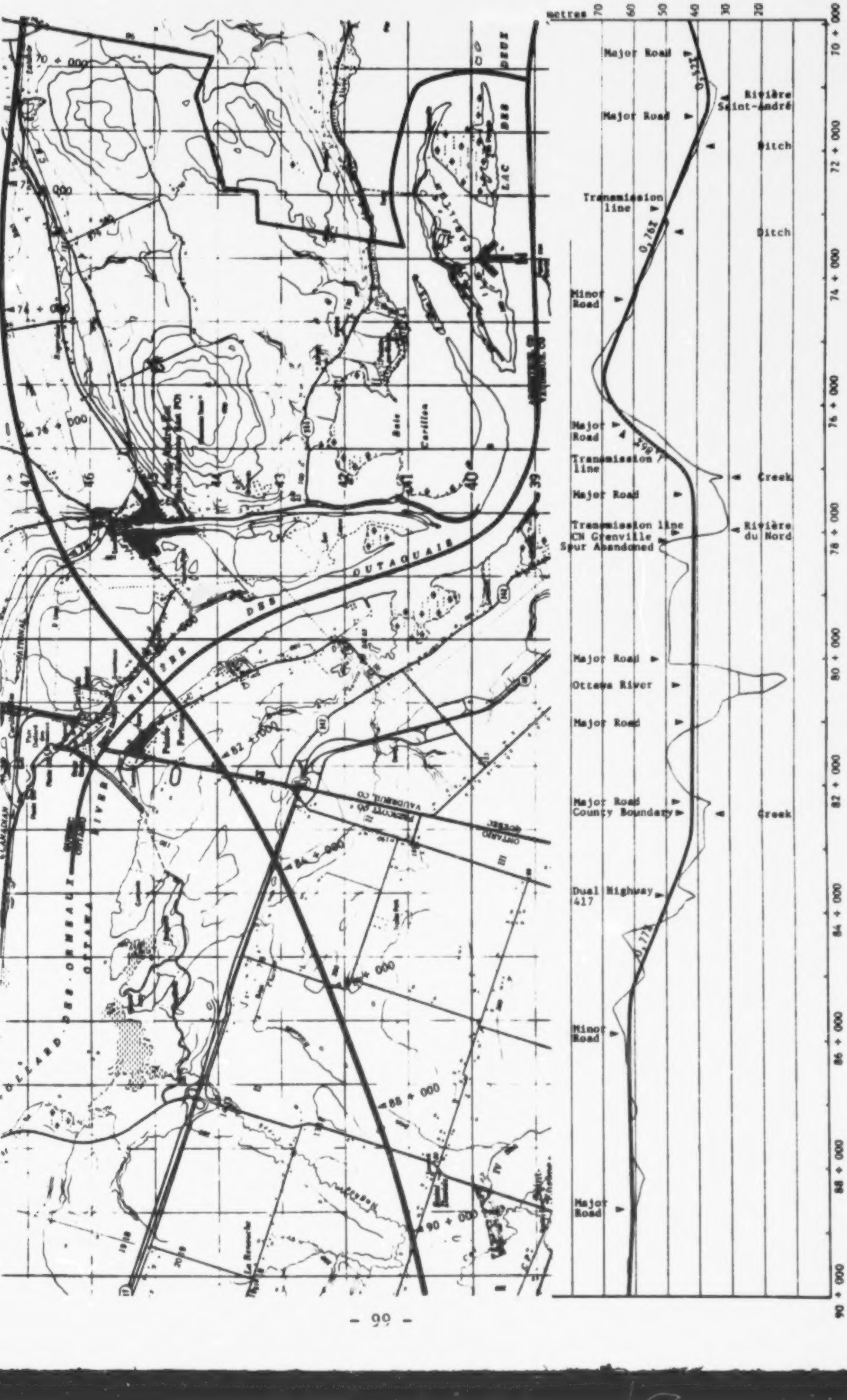
After leaving the CN right-of-way, the route crosses Rivière Saint-André, three major roads (one being grade-separated), two creeks and two sets of power transmission lines before reaching Quebec Highway 327 at km 77+350. This road crossing requires two expropriations and has to be grade-separated.

At km 78 the alignment crosses Rivière du Nord on a new bridge approximately 100 m long, simultaneously crossing a set of three transmission lines. On the west side of the river, the alignment crosses another power transmission line.

The Ottawa River is crossed with a 725 m long bridge which is the most important structure required on the rail route between Montreal and Ottawa. On the east side of the Ottawa River, crossing of Québec Highway 344 will have to be grade-separated. On the western bank, a major road is also crossed where a grade-separation is needed but no expropriation is necessary.

After km 82, one major road (requiring a grade separation) and one creek are crossed and the route enters Ontario. At km 83+700, crossing Highway 417, a limited-access expressway, requires an elaborate grade-separation. From that point to the end of this map section at km 91, the alignment crosses two minor roads and one major road which must be grade-separated. The route changes its heading progressively toward the West.

FIGURE D-6 OTTAWA RIVER CROSSING


metres
70
60
50
40
30
20
Major Road
Rivière Saint-André
Major Road
Ditch
Transmission line
Ditch
Minor Road
Major Road
Transmission line
Creek
Major Road
Transmission line
CN Grenville Spur Abandoned
Rivière du Nord
Major Road
Ottawa River
Major Road
Major Road
County Boundary
Creek
Dual Highway 417
Minor Road
Major Road
70 + 000
72 + 000
74 + 000
76 + 000
78 + 000
80 + 000
82 + 000
84 + 000
86 + 000
88 + 000
90 + 000
RIVIÈRE DES OUTAOUAIS
OTTAWA RIVER
LAC DES DEUX
Baie Carillon

D.7 Vankleek Hill Area (Figure D-7)

For this map section, the general direction followed by the alignment is slightly north of West.

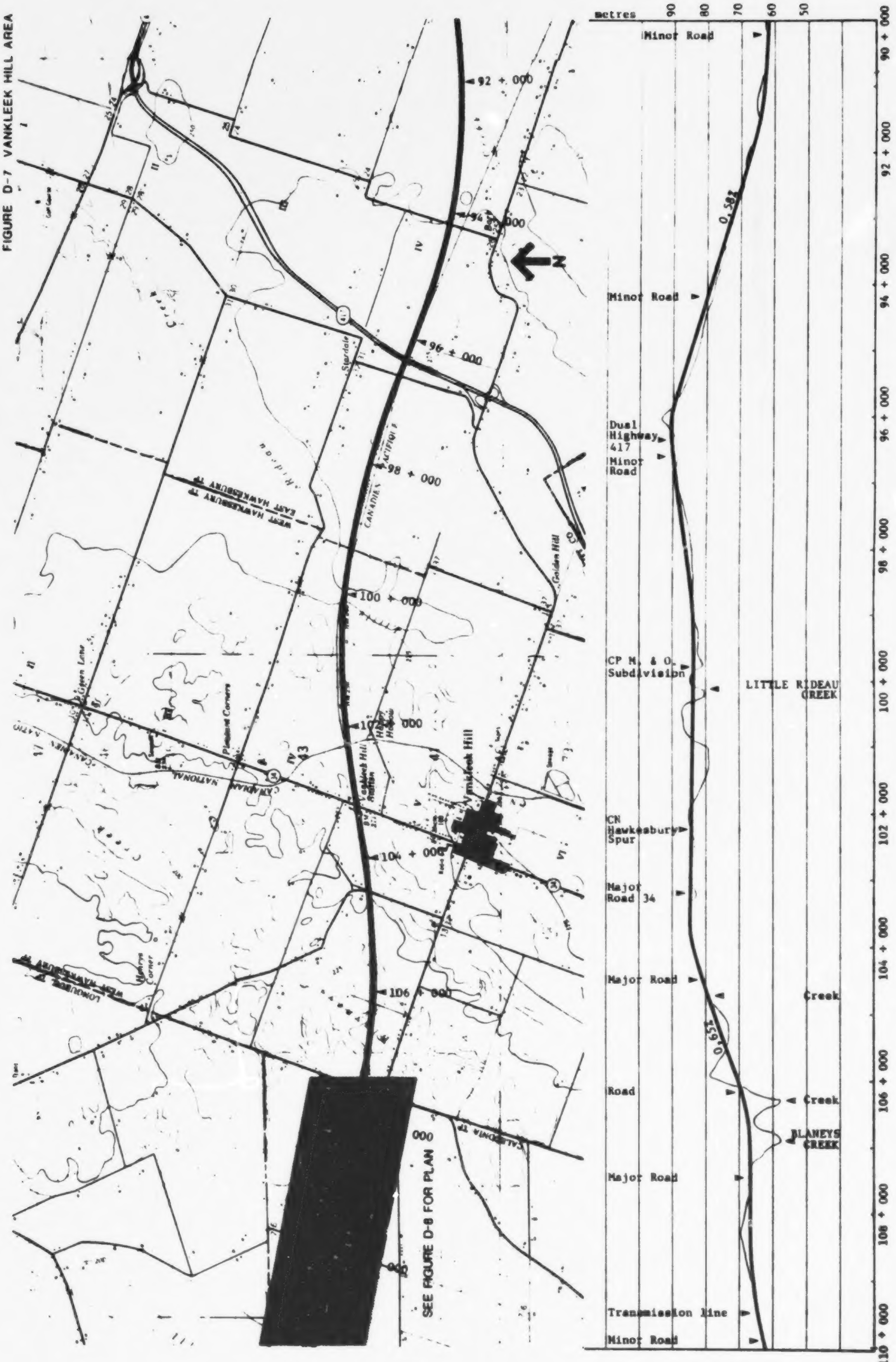
After crossing one minor road at km 94+200, the route joins the CP Subdivision M.&O. and runs south of the existing track after crossing it. Due to light freight traffic, this crossing does not have to be grade-separated.

From km 96 to km 108 approximately, the existing track will have to be rebuilt to follow the geometry of the two high speed tracks. The existing grade-separation, on which Highway 417 passes over the CP track, provides room for three tracks and will be enlarged to permit construction of two more tracks. A new ramp may have to be built to eliminate existing grade crossing just west of the grade separation.

From km 96+600 to the end of this map section at km 111+400, the route crosses a total of four streams which require culverts. It crosses one minor road that could be closed and one private road that will be considered as a farm crossing. Three major roads will be grade-separated using typical road-over-rail crossings. One of them is Ontario Highway 34 which is crossed less than two km north of Vankleek Hill, near Vankleek Hill CP Station at km 103+200. One set of transmission lines is also crossed in this section.

Apart from the CP line, the alignment crosses a CN track in Vankleek Spur of CN Subdivision Alexandria at km 102+250. This rail crossing requires adequate signalling for safe operation; it does not have to be grade-separated due to the very light traffic on the CN track. Movement on the CN line would be subordinated to movements on the Rail route.

FIGURE D-7 VANKLEEK HILL AREA


92 + 000
94 + 000
96 + 000
98 + 000
100 + 000
102 + 000
104 + 000
106 + 000
N
WEST HAWKESBURY TP
EAST HAWKESBURY TP
CANADIAN PACIFIC
CANADIAN NATIONAL
Vankleek Hill
Pleasant Corners
Green Lane
Golden Hill
Stardale
SEE FIGURE D-8 FOR PLAN
metres
90
80
70
60
50
Minor Road
Minor Road
Dual Highway 417
Minor Road
CP M. & O. Subdivision
LITTLE RIDEAU CREEK
CN Hawkesbury Spur
Major Road 34
Major Road
Creek
Road
Creek
BLANEYS CREEK
Major Road
Transmission line
Minor Road
0.58%
0.65%
90 + 000
92 + 000
94 + 000
96 + 000
98 + 000
100 + 000
102 + 000
104 + 000
106 + 000
108 + 000
110 + 000

D.8 Alfred Bog Area (Figure D-8)

From km 111+400 to Ottawa, the maps are realigned: base maps for Figures D-8 to D-11 are the same as base maps for Figures C-8 to C-11. As a result, a section of the Rail route is shown on Figures D-7 and D-8. That overlap is described in the present section.

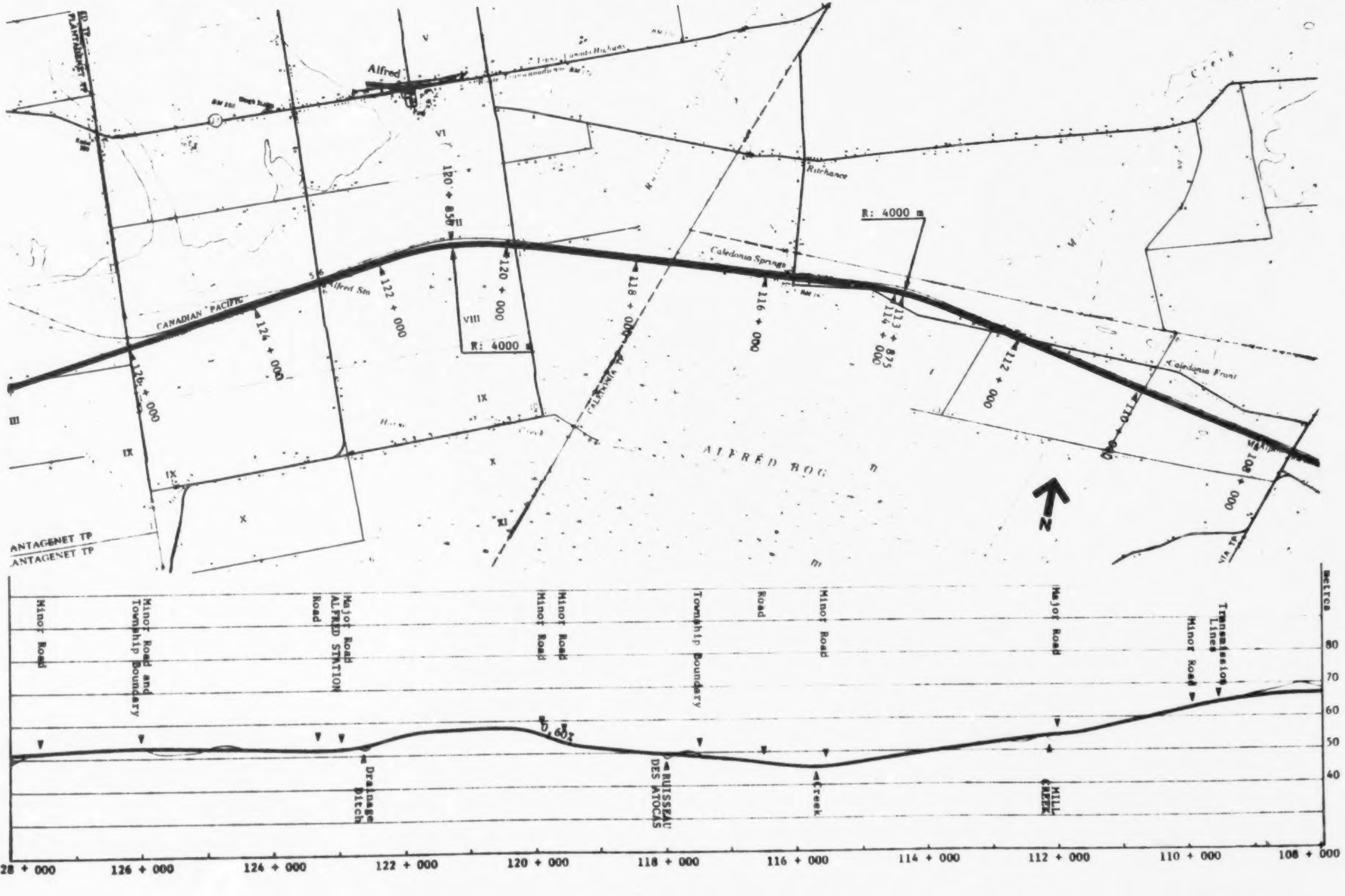
Descending from a limestone plain, the route passes through Caledonia Front and Caledonia Springs amongst mixed sand, clay and peat deposits. The route skirts the northern edge of Alfred Bog and, after two 4000 m radius curves, it heads Southwest. The first curve is centered around km 113+875. It is followed by a tangent of 5,5 km and the second curve is located at km 120+850. At km 125+500, the Rail route leaves the CP right-of-way and continues straight; this straightening is necessary to permit a 250 km/h speed.

In this map section (from km 111+400) the alignment crosses seven minor roads and two major roads; three of them will be grade-separated using typical road-over-rail crossings; the others will be candidate for closure or detour. Two expropriations are needed in this map section.

Four creeks are crossed; this will require two bridges and two culverts; 3,83 ha of woodland will require clearing to provide right-of-way for 2,55 km of the alignment.

The siding at Alfred Station must be moved north of the existing tracks; two expropriations are needed there. Two more expropriations are needed for the new right-of-way around km 127+500.

FIGURE D-8 ~~VANKLEEK HILL AREA~~ ALFRED BOG


Alfred
Ritchance
Caledonia Springs
Caledonia Front
ALFRED BOG
CANADIAN PACIFIC
Alfred Stn
R: 4000 m
R: 4000 m
PLANTAGENET TP
ANTAGENET TP
ANTAGENET TP
N
108 + 000
110 + 000
112 + 000
113 + 875
114 + 000
116 + 000
118 + 000
120 + 000
120 + 850
122 + 000
124 + 000
126 + 000
metres
80
70
60
50
40
Transmission Lines
Minor Road
Major Road
MILL CREEK
Minor Road
Creek
Road
Township Boundary
RUISSEAU DES ATOCAS
Minor Road
Minor Road
0.60%
Drainage Ditch
Major Road
ALFRED STATION
Road
Minor Road and Township Boundary
Minor Road
128 + 000
126 + 000
124 + 000
122 + 000
120 + 000
118 + 000
116 + 000
114 + 000
112 + 000
110 + 000
108 + 000

D.9 Plantagenet - Bourget Area (Figure D-9)

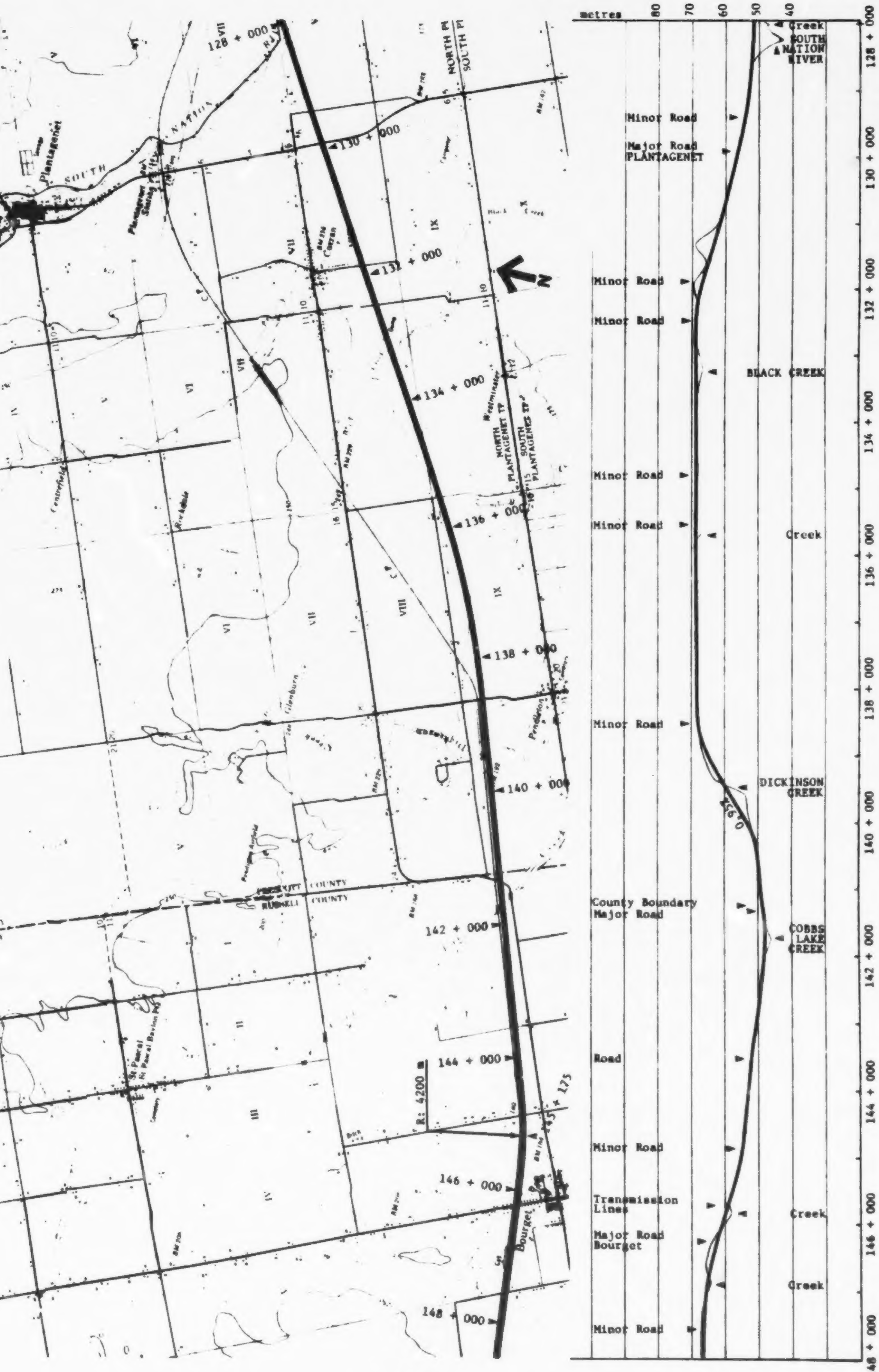
In this map section, the alignment crosses South Nation River, proceeds south of Curran and joins the CP right-of-way again, north of Pendleton. Then it descends toward Cobbs Lake, runs north of Bourget and leaves the map section at km 148+550. First entering the map on a southwest heading, it leaves it almost due West.

The South Nation River crossing requires a bridge of approximately 100 m in length; one expropriation is needed on the western bank of the river. Cobbs Lake Creek crossing also requires construction of a bridge that would be 40 m long. Five other water courses are crossed that will require culvert work; a sixth one will require a small bridge. The only curve in this map section is centered at km 45+175; its radius of 4200 m allows maximum operating speed.

The alignment crosses three major roads and nine minor roads in this section of the route. Four of those will be grade-separated using typical road-over-rail crossings. The seven others are candidate for closure or detour; the last one, a private road, will be treated as a farm crossing. One set of transmission lines is also crossed.

North of Bourget, the access road to the CP Station might have to be moved to provide clearance for the rail route. Along with that, two expropriations are needed in this area.

FIGURE D-9 PLANTAGENET-BOURGET AREA


128 + 000
130 + 000
132 + 000
134 + 000
136 + 000
138 + 000
140 + 000
142 + 000
144 + 000
146 + 000
148 + 000
R: 4200 m
Plantagenet
SOUTH NATION
Curran
NORTH PLANTAGENET TP
SOUTH PLANTAGENET TP
PRESCOTT COUNTY
RUSSELL COUNTY
Bourget
St Pascal
Glenburn
Pendleton
Centrefield
metres
80
70
60
50
40
Creek
SOUTH NATION RIVER
Minor Road
Major Road PLANTAGENET
Minor Road
Minor Road
BLACK CREEK
Minor Road
Minor Road
Creek
Minor Road
DICKINSON CREEK
0.25%
County Boundary
Major Road
COBBS LAKE CREEK
Road
Minor Road
Transmission Lines
Creek
Major Road Bourget
Creek
Minor Road

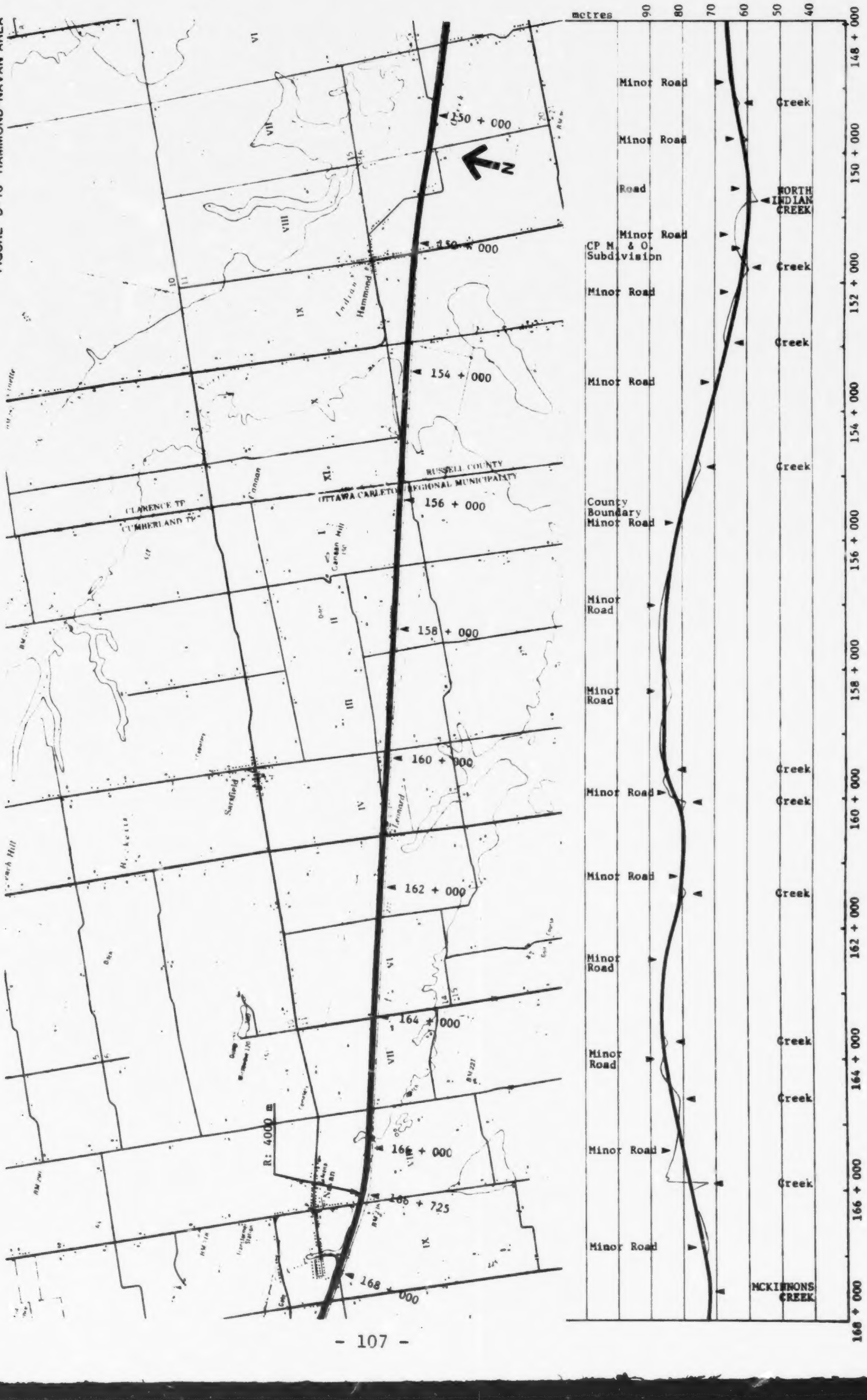
D.10 Hammond-Navan Area (Figure D-10)

The alignment runs south of Hammond and Canaan Hill. It then proceeds through Leonard (south of Sarsfield). It enters a 4000 m radius curve at km 166+725, one km south of Navan and leaves this map section at km 168+750. The passenger tracks cross the existing track at km 151+250 and are built north of it until Ottawa.

A total of seventeen minor roads are crossed in this route section. Eight roads will be grade-separated and nine will be candidates for closure or detour. Rail sidings on the south side of the present track are found at Leonard and Navan; they will be preserved, but the section buildings will be relocated.

Twelve creeks are crossed in this section. Except for the creek located at km 165+850, which requires a small bridge, they can all be crossed with culverts.

FIGURE D-10 HAMMOND-NAVAN AREA


150 + 000
152 + 000
154 + 000
156 + 000
158 + 000
160 + 000
162 + 000
164 + 000
166 + 000
166 + 725
168 + 000
R: 4000 m
RUSSELL COUNTY
OTTAWA CARLETON REGIONAL MUNICIPALITY
CLARENCE TP
CUMBERLAND TP
Hammond
Indian
Cannan
Canaan Hill
Sarsfield
Leonard
Navan
N
metres
90
80
70
60
50
40
148 + 000
150 + 000
152 + 000
154 + 000
156 + 000
158 + 000
160 + 000
162 + 000
164 + 000
166 + 000
168 + 000
Minor Road
Creek
Road
NORTH INDIAN CREEK
CP M. & O. Subdivision
County Boundary
MCKINNONS CREEK

D.11 Ottawa Area (Figure D-11)

The alignment enters this map section at km 168+750. It runs on the northern edge of Mer Bleue passing south of Notre-Dame-des-Champs. At km 174 it enters a curve of 4000 m radius and leaves it with a heading approximately fifteen degrees south of West.

The alignment passes Highway 417, then it enters an industrial zone in Ottawa. After two curves of opposite direction the route arrives at Ottawa Station at km 185+000. Those curves have a radius of 3000 m and are separated by a tangent of more than 1 km.

In this map section, four creeks are crossed with culverts; two sets of power transmission line are also crossed.

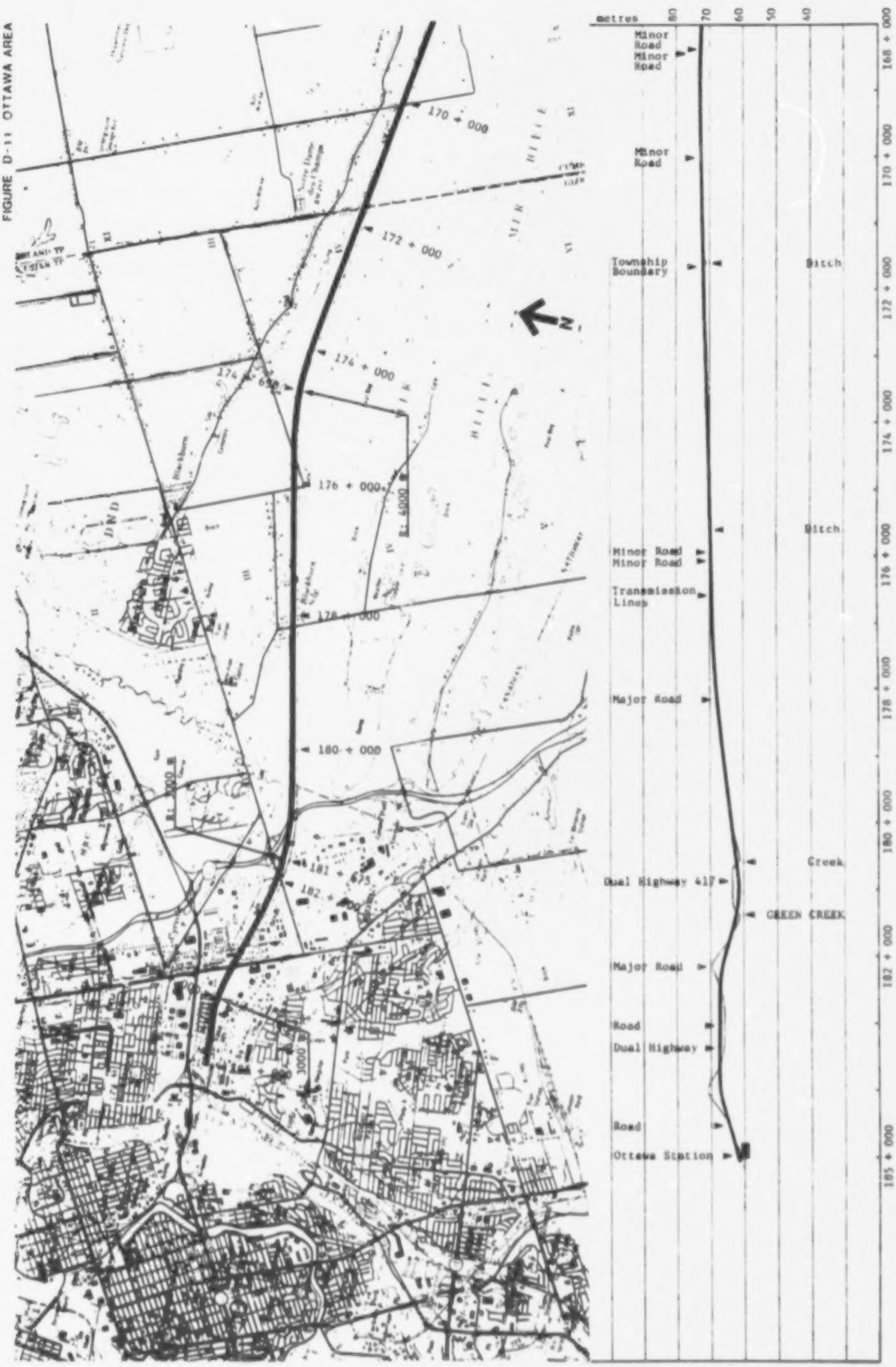
At km 170, due to its function, one minor road will be grade-separated. Around km 176, one minor road which crosses the track twice has to be moved north of the right-of-way; a grade separation is still needed. Anderson Road is crossed at km 178+150: this crossing will also be grade-separated.

The structure carrying Highway 417 over CP Subdivision M. & O. will be enlarged to permit the construction of two more tracks. At km 181+675, a siding on the north side will have to be eliminated; this may mean compensation to the industry served and to CP.

From that point to the station, the route successively crosses Innes Road and Michael and Triole Streets. Then it passes under St. Lawrence Boulevard, an important arterial with four lanes. Finally, the route crosses Belfast Road before entering the Ottawa Station.

Innes Road and Michael Street will have to be carried over the three tracks with a new road-over-rail structure. Triole Street will be closed. The structure carrying St. Lawrence Boulevard over the tracks will have to be rebuilt, as well as that at Belfast Road.

FIGURE D-11 OTTAWA AREA



170 + 000
172 + 000
174 + 000
174 + 650
176 + 000
178 + 000
180 + 000
181 + 675
182 + 000
R: 4000 m
R: 3000 m
R: 3000 m
N
metres
80
70
60
50
40
Minor Road
Minor Road
Minor Road
Township Boundary
Ditch
Ditch
Minor Road
Minor Road
Transmission Lines
Major Road
Creek
Dual Highway 417
GREEN CREEK
Major Road
Road
Dual Highway
Road
Ottawa Station
168 + 000
170 + 000
172 + 000
174 + 000
176 + 000
178 + 000
180 + 000
182 + 000
185 + 000

E. RAILWAY SYSTEM DOCUMENTATION

This appendix provides complementary information and supporting material on the definition of the Rail system presented in Chapter 5. Material is presented herein in the same order as in that chapter.

E.1 Line Capacity

This section corresponds to Section 5.3, and is subdivided into three sub-sections as follows: capacity requirement, load factor and capacity adjustment, trip time calculation.

E.1.1 Capacity Requirement

Table E-1, for which the first block of columns is obtained by interpolation from Table 1-14, presents the annual traffic forecasts and the directional daily and peak-period traffic loads that can be derived from them to serve as a basis for system definition.

The process starts with the annual bi-directional traffic forecasts shown at left in Table E-1. First, it was presumed that directional (one-way) traffic was exactly half of total traffic. Daily directional traffic was assumed equal to annual directional traffic divided by 300, as this provides a better indication of a typical day than dividing by 365.

To reflect the significant concentration of trips that will occur in peak periods, it was presumed that 33% of daily departures will take place in each of two peak periods of two hours and fifteen minutes.

When taken over the most heavily-loaded segment of the Montreal - Mirabel - Ottawa route, which is the link between Mirabel and the suburban station, this volume constitutes the line capacity requirement for system definition. This is shown in the second block of columns in Table E-1 and discussed in greater detail below.

E.1.2 Load Factor and Capacity Adjustment

In Chapter 2, the basic train consist was defined as containing a number of seats equivalent to five LRC coaches, that is nearly 400 seats. It must now be checked that this provides the required capacity, which is shown in Table E-1.

Based on Table 1-14, the expected Rail traffic will be between 1 151 000 and 1 414 000 person-trips per year in both directions, in 1991. This implies, dividing by 300 and then by two, a typical daily directional traffic between 1918 and 2357 person-trips on the most-highly loaded trip leg.

To reflected the expected significant concentration of these trips during peak periods, it will be presumed that 33% will take place each of two 2-hour peak periods. As a result, 640 to 786 persons would want to travel daily in each direction during the peak period in 1991. In 2001, the corresponding range would be 919 to 1141 persons, in 2011, 979 to 1218.

With a minimum interval of 45 min, four trains will leave each terminal during each 2h15 peak period. If each train has a 400-seat capacity, the load factor would be 40,0 to 49,1% in 1991, 57,4 to 71,3% in 2001, and 62 to 76,1% in 2011. Some of these peak-hour load factors appear low and the consist capacity should be reduced from 1991 to 2001.

For system definition, the train capacity must be better adapted to demand, to maintan a reasonable load factor. As a result, from 1991, train capacity will be 300 seats in four coaches, raising the load factor to between 53,3 and 65,5% during the peak period in 1991 and higher values thereafter.

In 1999, consist capacity is increased to 375 seats in five coaches; the peak load factor is between 56,9 and 70,5%. By 2011, with the same consist capacity, the load factor will reach a value between 65,3 and 81,2%.

Table E-1

Rail Capacity Requirements and Load Factors

Year	Annual Bi-Directional Traffic (1,2) (1000 person-trips)		Peak-Period Traffic (3,4) (person-trips directional)		Capacity (5) (seats/train)	Load Factor (6) (%)	
	Minimum	Maximum	Minimum	Maximum		Minimum	Maximum
1991	1 151	1 414	640	786	300	53	66
1992	1 194	1 469	663	816	300	55	68
1993	1 237	1 523	687	846	300	57	71
1994	1 283	1 581	713	878	300	59	73
1995	1 330	1 640	739	911	300	62	76
1996	1 378	1 702	765	945	300	64	79
1997	1 430	1 768	794	982	300	66	82
1998	1 483	1 836	824	1 020	300	69	85
1999	1 537	1 906	854	1 058	375	57	71
2000	1 595	1 979	886	1 100	375	59	73
2001	1 654	2 055	919	1 141	375	61	76
2002	1 694	2 105	942	1 169	375	63	78
2003	1 720	2 138	955	1 187	375	64	79
2004	1 735	2 159	964	1 200	375	64	80
2005	1 747	2 173	971	1 207	375	65	80
2006	1 754	2 181	975	1 212	375	65	81
2007	1 756	2 186	976	1 214	375	65	81
2008	1 759	2 188	977	1 215	375	65	81
2009	1 761	2 191	978	1 217	375	65	81
2010	1 763	2 193	979	1 218	375	65	81
2011	1 763	2 194	979	1 218	375	65	81

Notes:
1. The annual traffic forecast is the number of thousands of bi-directional person trips between the suburban station and Mirabel.
2. The annual traffic includes intercity traffic (base and induced) as well as airport-related traffic (base and induced): Table 1-14.
3. The peak period directional traffic is obtained by dividing the annual bi-directional traffic first by two (to obtain annual directional traffic for a typical weekday) then by 3.
4. West Island - Mirabel link, 6h30 to 8h45 or 16h15 to 18h30.
5. Unit capacity is 75 passengers per car.
6. Total peak period capacity is four times train capacity (4 trains / peak period).

Capacity and consist size adjustment are shown at right in Table E-1, which constitutes the basis for Figure 5-1.

Travel time between Montreal and Ottawa, with 90 s station stops at the suburban station and at Mirabel Airport has been calculated at 70 minutes with a maximum lateral acceleration of 0,7 m/s^2 implying speed restrictions in curves. This is explained in E.1.3 below.

Based on this information, the train traffic pattern will be as in Table E-2 for the design period; the information displayed in Table E-2 is the basis for Figure 5-2. It shows that six trainsets are needed for operation.

E.1.3 Trip Time

Trip time between Montreal, Mirabel and Ottawa was calculated using the Rail route characteristics described in Appendix C and summarized in Table E-3, together with the performances (resistance, tractive effort, acceleration, and braking) given for the assumed vehicle in Section E.2. Other assumptions used in this calculation are the following:

- station dwell time of 90 s;
- grades under 0,4% not taken into account in the calculation;
- operating speed presumed never to exceed 200 km/h in normal operation;
- modern operating policy eliminating delays associated with conventional operating practices;
- push-pull operation;
- speed restrictions through curves based on a maximum lateral acceleration of 0,7 m/s^2, which corresponds to the comfort limit with a 6° superelevation.

Results of the trip time calculation are given in Table E-4 and discussed in Sub-section E.2.7.

Table E-2

Rail Schedule and Consist Assignment

From Montreal					From Ottawa				
Trip Number	Consist I.D.	Departure Time	Arrival Time	Layoff Time	Trip Number	Consisit I.D.	Departure Time	Arrival Time	Layoff Time
1	A	6h30	7h40	1h15	2	D	6h30	7h40	1h15
3	B	7h15	8h25	2h15	4	E	7h15	8h25	2h15
5	C	8h00	9h10	1h50	6	F	8h00	9h10	1h50
7	D	8h45	9h55	2h35	8	A	8h45	9h55	2h35
9	E	9h30	10h40	2h50	10	B	9h30	10h40	2h50
11	F	11h00	12h10	2h50	12	C	11h00	12h10	2h50
13	A	12h30	13h40	2h35	14	D	12h30	13h40	2h35
15	B	13h30	14h40	2h20	16	E	13h30	14h40	2h20
17	C	15h00	16h10	1h35	18	F	15h00	16h10	1h35
19	D	16h15	17h25	3h05	20	A	16h15	17h25	3h05
21	E	17h00	18h10	2h20	22	B	17h00	18h10	2h20
23	F	17h45	18h55	1h35	24	C	17h45	18h55	1h35
25	A	18h30	19h40	-	26	D	18h30	19h40	-
27	B	19h30	20h40	2h20	28	E	19h30	20h40	2h20
29	C	20h30	21h40	2h20	30	F	20h30	21h40	2h20
31	D	21h30	22h40	7h50	32	A	21h30	22h40	7h50
33	E	23h00	0h10	7h05	34	B	23h00	0h10	7h05
35	F	24h00	1h10	6h50	36	C	24h00	1h10	6h50

Table E-3

Rail Route Characteristics

Km from Central Station	Characteristics	Maximum Speed (km/h)
0	Central Station	0
0 300	Begin: +0,6% Grade	160
0 650	Curve, Radius: 1 000 m	160
5 100	End: +0,6% Grade; Begin: -0,5% Grade	160
9 000	End: -0,5% Grade	160
10 200	Curve, Radius: 1 200 m	160
16 000	West Island Station	0
16 300	Curve, Radius: 2 100 m	160
17 750	Curve, Radius: 1 000 m	160
23 100	Curve, Radius: 600 m	120
24 450	Curve, Radius: 600 m	120
25 550	Curve, Radius: 600 m	120
27 450	Curve, Radius: 850 m	120
28 625	Curve, Radius: 1 000 m	160
29 450	Curve, Radius: 1 800 m	200
34 050	Curve, Radius: 4 000 m	200
37 600	Curve, Radius: 3 100 m	200
43 700	Curve, Radius: 4 000 m	200
44 000	Begin: +0,4% Grade	200
48 550	Curve, Radius: 3 000 m	200
50 000	End: +0,4% Grade	-
	Mirabel Station	0
51 450	Curve, Radius: 3 000 m	200
56 000	End: -0,4% Grade	200
56 450	Curve, Radius: 4 000 m	200
59 450	Curve, Radius: 4 000 m	200
65 750	Curve, Radius: 4 000 m	200
76 000	Begin: +0,9% Grade	200
81 000	End: +0,9% Grade; Begin: -1,8% Grade	200
82 000	End: -1,8% Grade	200
88 000	Begin: +1,3% Grade	200
90 000	End: +1,3% Grade	200
97 000	Begin: +0,7% Grade	200
101 000	End: +0,7% Grade	200
109 000	Begin: -0,8% Grade	200
111 000	End: -0,8% Grade	200
118 875	Curve, Radius: 4 000 m	200
125 850	Curve, Radius: 4 000 m	200
143 500	Begin: -1,2% Grade	200
145 000	End: -1,2% Grade	200
150 175	Curve, Radius: 4 200 m	200
171 725	Curve, Radius: 4 000 m	200
180 100	Curve, Radius: 4 000 m	200
186 675	Curve, Radius: 3 000 m	200
189 000	Curve, Radius: 3 000 m	200
190 000	Ottawa Station	0

Table E-4

Trip Time Between Montreal, Mirabel and Ottawa, By Rail

Speed (km/h)	Route Link (km)	Time (s)	Cumulative Time (s)	Comment
Beginning-End	From - To			
	0,00	0,0	0	Central Station
0 - 60	0,00 - 0,29	34,1	34,1	-
60 - 160	0,29 - 3,54	97,4	131,5	+0,6% Grade
160 - 160	3,54 - 14,35	243,2	374,7	-
160 - 0	14,35 - 16,00	74,1	448,8	-
	16,00	90,0	538,8	West Island Station
0 - 160	16,00 - 18,88	113,3	652,1	-
160 - 160	18,88 - 22,38	78,8	730,9	-
160 - 120	22,38 - 23,10	18,5	749,4	-
120 - 120	23,10 - 28,63	165,7	915,1	Curves
120 - 200	28,63 - 34,98	134,6	1 049,7	-
200 - 200	34,98 - 47,43	224,1	1 273,8	-
200 - 0	47,43 - 50,00	92,6	1 366,4	-
	50,00	90,0	1 456,4	Mirabel Station
0 - 200	50,00 - 57,59	206,0	1 662,4	-
200 - 200	57,59 - 76,00	331,4	1 993,8	-
200 - 170	76,00 - 81,00	94,7	2 088,5	+0,9% Grade
170 - 200	81,00 - 84,95	76,3	2 164,8	-
200 - 200	84,95 - 88,00	54,9	2 219,7	-
200 - 180	88,00 - 90,00	43,4	2 263,1	+1,3% Grade
180 - 200	90,00 - 92,99	56,5	2 319,6	-
200 - 200	92,99 - 97,00	72,2	2 391,8	-
200 - 180	97,00 - 101,00	80,5	2 472,3	+0,7% Grade
180 - 200	101,00 - 103,99	56,5	2 528,8	-
200 - 200	103,99 - 187,43	1 501,9	4 030,7	-
200 - 0	187,43 - 190,00	92,6	4 123,3	-
	190,00	4 123,3	-	Ottawa Terminal

TOTAL TRIP TIME : 68,7 min

E.2 Vehicle Performance Definition

This section complements Section 5.4 and describes the performance of the assumed vehicle.

In order to calculate the expected trip time between Montreal, Mirabel and Ottawa, it was necessary to establish the acceleration and deceleration performance of the Rail vehicle. Rather than using the performance curves of a given vehicle, representative performance curves were defined; those curves were based on those of existing vehicles and were adapted to reflect a performance that is compatible with the performance criteria (Chapter 3), VIA's overall Concept Specification, and the principles for system definition adopted in this study (Section 5.1).

E.2.1 Review of Existing Trains

With this objective in mind, a brief analysis was made on the performance of eleven selected train consists, for which data was available; their acceleration characteristics are displayed in Table E-5. It shows that selected diesel-powered train achieve an average acceleration of 0,14 m/s^2 while selected electric trains achieve an average acceleration of 0,27 m/s^2. This value was retained to establish the performance of the vehicles for the Rail system. The time to reach 200 km/h with such an average acceleration is 206 seconds.

For normal service braking, a value of 0,6 m/s^2 was selected as the average deceleration between 200 km/h and 0 km/h. This value has been chosen as a result of typical service braking rates achieved by conventional rail equipment (Table E-6). Although braking rate is not constant through the 200-0 km/h speed range, an average constant value was retained as representative and sufficiently precise for the purpose of this study.

Table E-5

Acceleration Performance of Selected Trains

Type of Train	Country	Propulsion	Speed (km/h)	Time to reach speed (s)	Average Acceleration (m/s^2)
APT	U.K.	Electric	200	225	0,25
ETR 401	Italy	Electric	200	150	0,37
LRC	Canada	Diesel	145	275	0,15
961	Japan	Electric	200	170	0,33
TGV - PSE	France	Electric ?	200	380	0,15
SPV - 2000	U.S.A.	Diesel	160	240	0,19
HST	U.K.	Diesel	175	300	0,16
AEM-7 & 6 coaches	U.S.A.	Electric	200	180	0,31
AEM-7 & 8 coaches	U.S.A.	Electric	200	240	0,23
RDC (1 car)	U.S.A.	Diesel	145	515	0,08
RDC (2 cars)	U.S.A.	Diesel	160	420	0,11

Notes: Average acceleration for diesel trains: 0,14 m/s^2
electric trains: 0,27 m/s^2
Average time to reach 200 km/h for electric trains: 206 s.

E.2.2 Selection of Car Weight

A unit weight of 750 kg/m^2 was used to estimate the empty vehicle weight, which results in a tare of 62 tonnes. This is based on a review of weight of modern rail vehicles. This compares to approximately 48 tonnes for an LRC or Amfleet coach, 70 tonnes for a Metroliner (intercity self-propelled electric car), and 46 tonnes for a Silverliner (self-propelled electric commuter car).

By adding the weight of 75 passengers at 80 kg (including luggage), the total weight of each car would come out to 68 tonnes. This value is used to calculate the required power.

E.2.3 Train Resistance Calculation

The train resistance is calculated using the following Davis-type formula for multiple-unit consist:

$$R = 1{,}3 + 29\ (N / W) + 0{,}45\ (V / 10) + (C / W)\ (A / 100)\ (V / 10)^2$$

Where R: resistance (lbs./ton)
N: number of axles
W: weight of vehicle (tons)
C: aerodynamic coefficient
A: frontal area (sq. ft.)
V: speed (mph)

For a 5-car consist and with the following values for the parameters,

N: 4
W: 75 tons (69 tonnes)
A: 110 sq. ft.
C: 24,0 for leading car
3,4 for trailing cars

Table E-6

Typical Service Braking Rates for Conventional Railway Equipment

	3 RDC		Locomotive & 3 coachs		6 M.U.		6 M.U.		LRC Specification		
	Distance (f.)	a (m/s^2)	Distance (f.)	a (m/s^2)	Distance (f.)	a (m/s^2)	Distance (f.)	a (m/s^2)	Speed (mph)	Distance (f.)	a (m/s^2)
40	1 035	0,507	1 110	0,473	970	0,541	1 015	0,517	50	1 600	0,512
50	1 430	0,573	1 700	0,482	1 380	0,594	1 380	0,594	75	3 250	0,567
60	1 900	0,621	2 330	0,507	1 850	0,638	1 810	0,652	100	5 700	0,575
70	2 400	0,669	3 120	0,515	2 360	0,681	2 250	0,714	125	8 700	0,589
80	2 950	0,711	4 070	0,516	2 920	0,719	2 710	0,774	-	-	-
90	3 560	0,746	-	-	-	-	-	-	-	-	-
Average Deceleration (m/s^2)	0,638		0,499		0,635		0,650		0,561		

Note: Average: 0,6 m/s^2.
Source: CN and LRC-2-78 Specifications.

the resistance formula becomes, in SI System:

$$R_N = 4\,754 + 466{,}6\ (V / 10) + 70{,}94\ (V / 10)^2$$

where the resistance is expressed in Newtons and the speed in km/h.

Calculated values of resistance are given in Table E-7. At 200 km/h, the resistance is 42,5 kN for a five-car consist. This compares to 32,1 kN for the French TGV; 48,1 kN for a standard French train; and 35,3 kN for the British HST (2 + 7 formation).

E.2.4 Tractive Effort Characteristics

Based on the average acceleration performance requirements established previously, tractive effort characteristics were developed. The tractive effort curve for a five-car consist is shown in Figure E-1.

Parameters given in Table E-9 were calculated using the following formula:

$$a = TE\ net\ /\ 1{,}1\ *\ W\ *\ 9{,}81$$

The parameter definitions are given in Table E-8.

The results given in Table E-9 are illustrated with series of graphs as follows:

Figure E-2: Acceleration as a function of Speed
Figure E-3: Speed and Distance as a function of Time
Figure E-4: Power, Power Factor, and Efficiency as a function of Speed.

Table E-7

Calculated Values of Resistance as a Function of Speed

Speed (km/h)	Rolling and Friction resistance (kN)	Air Resistance (kN)	Total Resistance (kN)
0	4,75	0,00	4,75
5	4,99	0,02	5,01
15	5,45	0,16	5,61
25	5,92	0,44	6,36
35	6,39	0,87	7,26
45	6,85	1,44	8,29
55	7,32	2,15	9,47
65	7,79	3,00	10,79
75	8,25	4,00	12,25
85	8,72	5,13	13,85
95	9,19	6,40	15,59
105	9,65	7,82	17,47
115	10,12	9,38	19,50
125	10,59	11,08	21,67
135	11,05	12,93	23,98
145	11,52	14,92	26,44
155	11,99	17,04	29,03
165	12,45	19,31	31,76
175	12,92	21,73	34,65
185	13,39	24,28	37,67
195	13,85	26,97	40,82
200	14,09	28,38	42,47

Note: Resistance values are given for a five-car consist.

Table E-8

Parameter Definition for Acceleration Calculations

$$a = TE\ net \div 1{,}1 * W * 9{,}81$$

TE net: $TE - R$

Δt : $\Delta S/a$

Δd : $(S_F^2 - S_i)^2 / 2 * a$

RPCS : $R * S$

RPA : $TE * S$

CPCS : $(R * S) / N * PF$

CPA : $(TE * S) / N * PF$

Where : a : acceleration
TE : tractive effort (at rail)
R : resistance
TE net: net tractive effort (at rail)
Δt : time increment
Δd : distance increment
S_F : final speed
S_i : initial speed
RPCS : rail power at constant speed
RPA : rail power in acceleration
CPCS : power at catenary at constant speed
CPA : power at catenary at acceleration
N : efficiency
PF : power factor
W : weight of cars
1,1 : ratio taking account rotational effects.

Table E-9

Performance and Power Characteristics of the Rail Technology (Acceleration)

S km/h	a (m/s²)	TEnet (kN)	R (kN)	TE (kN)	Δt (s)	t (s)	Δd (m)	d (m)	N	PF	N·PF	RPCS (kW)	RPA (kW)	CPCS (kVA)	CPA (kVA)
0						0,0		0							
	0,495	185,0	5,0	190	5,6		8		0,35	0,28	0,10	7	264	70	2640
10						5,6		8							
	0,493	184,4	5,6	190	5,6		23		0,50	0,35	0,18	23	792	128	4400
20						11,2		31							
	0,491	183,6	6,4	190	5,7		39		0,60	0,45	0,27	44	1319	163	4885
30						16,9		70							
	0,489	182,7	7,3	190	5,7		55		0,66	0,60	0,40	71	1847	178	4618
40						22,6		125							
	0,486	181,7	8,3	190	5,7		71		0,71	0,78	0,55	104	2375	189	4318
50						28,3		196							
	0,483	180,5	9,5	190	5,8		88		0,73	0,70	0,51	145	2903	284	5692
60						34,1		284							
	0,479	179,2	10,8	190	5,8		105		0,76	0,73	0,56	195	3431	348	6127
70						39,9		389							
	0,475	177,7	12,3	190	5,8		122		0,78	0,76	0,59	256	3958	434	6708
80						45,7		511							
	0,471	176,1	13,8	190	5,8		139		0,80	0,79	0,63	328	4486	521	7120
90						51,6		650							
	0,466	174,4	15,6	190	6,0		157		0,81	0,83	0,67	412	5014	729	7417
100						57,6		808							
	0,429	160,5	17,5	178	6,5		189		0,82	0,85	0,70	510	5192	729	7417
110						64,1		997							
	0,381	142,5	19,5	162	7,3		233		0,83	0,85	0,71	623	5175	877	7289
120						71,4		1230							
	0,340	127,3	21,7	149	8,2		284		0,84	0,85	0,71	753	5174	1061	7287
130						79,6		1514							
	0,300	112,0	24,0	136	9,3		347		0,84	0,85	0,71	900	5100	1268	7183
140						88,9		1861							
	0,250	93,0	26,4	120	11,1		447		0,84	0,85	0,71	1063	4833	1497	6807
150						100,0		2308							
	0,209	78,0	29,0	107	13,3		572		0,84	0,85	0,71	1249	4607	1759	6489
160						113,3		2880							
	0,169	63,2	31,8	95	16,4		753		0,84	0,85	0,71	1457	4354	2052	6132
170						129,7		3633							
	0,140	52,3	34,7	87	19,8		965		0,84	0,85	0,71	1687	4229	2376	5956
180						149,5		4598							
	0,110	41,3	37,7	79	25,3		1298		0,84	0,85	0,71	1937	4060	2728	5718
190						174,8		5896							
	0,089	33,2	40,8	74	31,2		1691		0,84	0,85	0,71	2210	4008	3113	5645
200						206,0		7587							
			42,5	72					0,84	0,85	0,71	2361	4000	3325	5634

Note: Performance is given for a five-car consist on dry level tangent track.

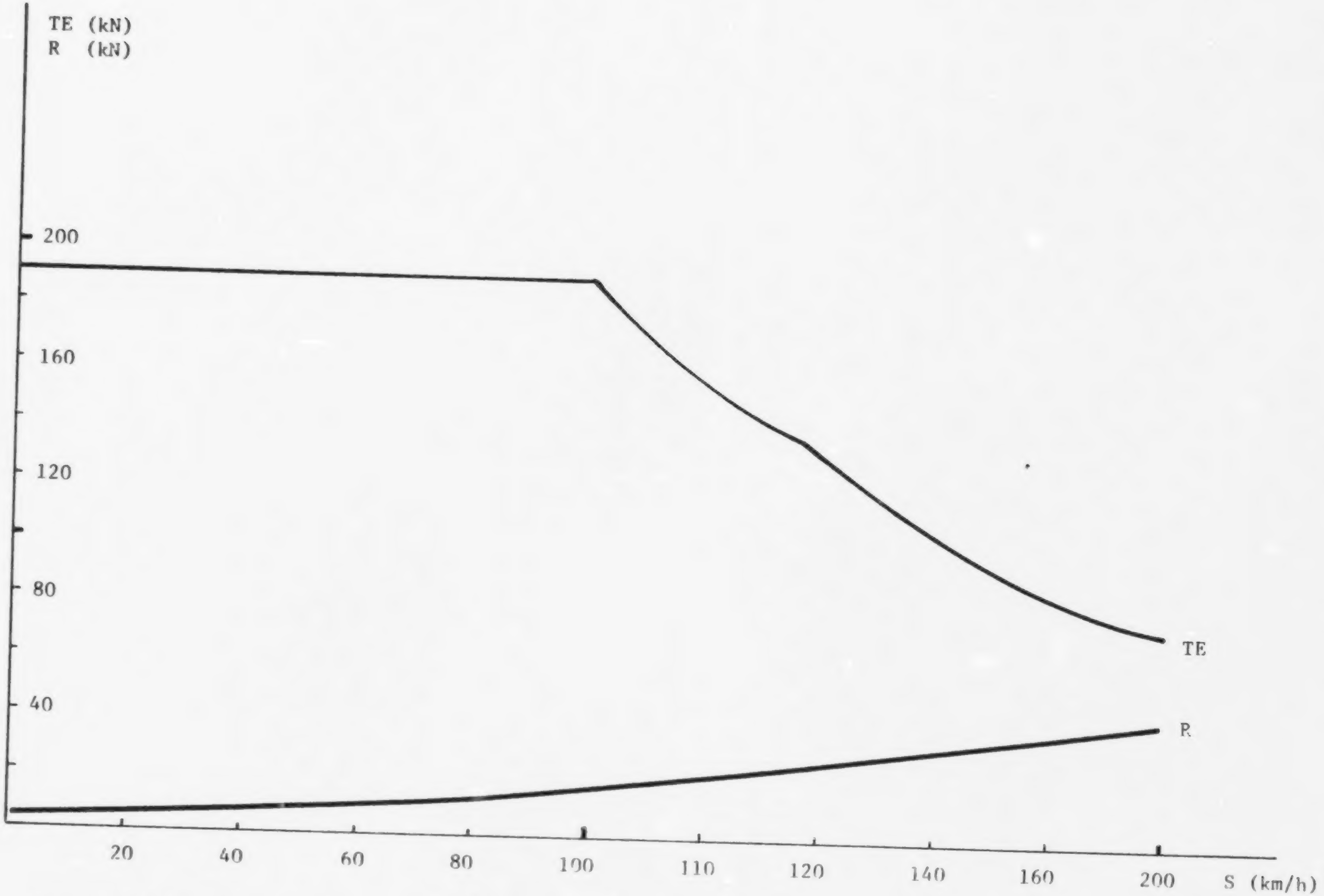


Figure E-1 Tractive Effort and Resistance as a Function of Speed
(Dry Level Tangent Track, Five-Car Consist)

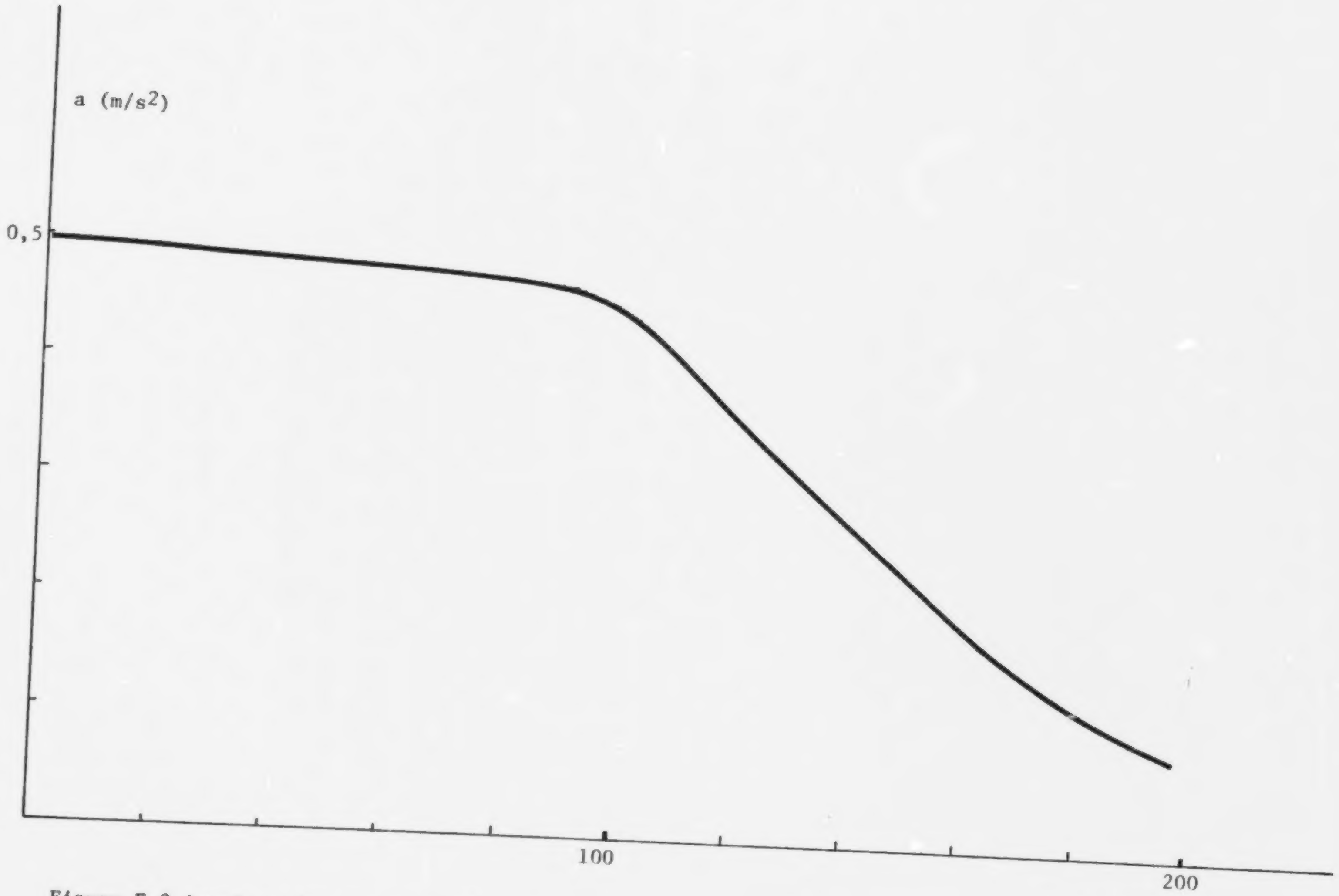


Figure E-2 Acceleration as a Function of Speed
(Dry Level Tangent Track, Five-Car Consist)

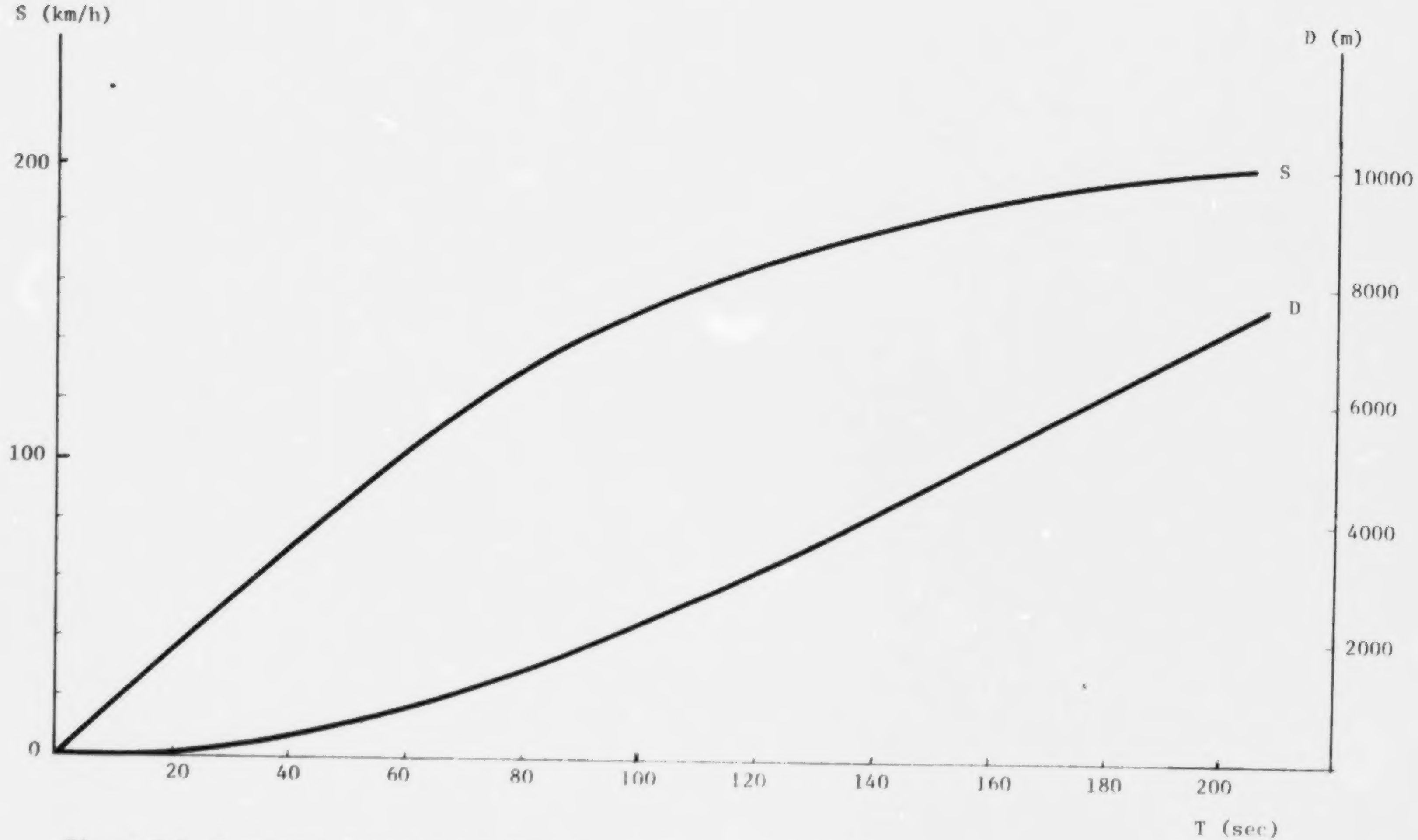


Figure E-3 Speed and Distance as a Function of Time: Acceleration (Dry Level Tangent Track, Five-Car Consist)

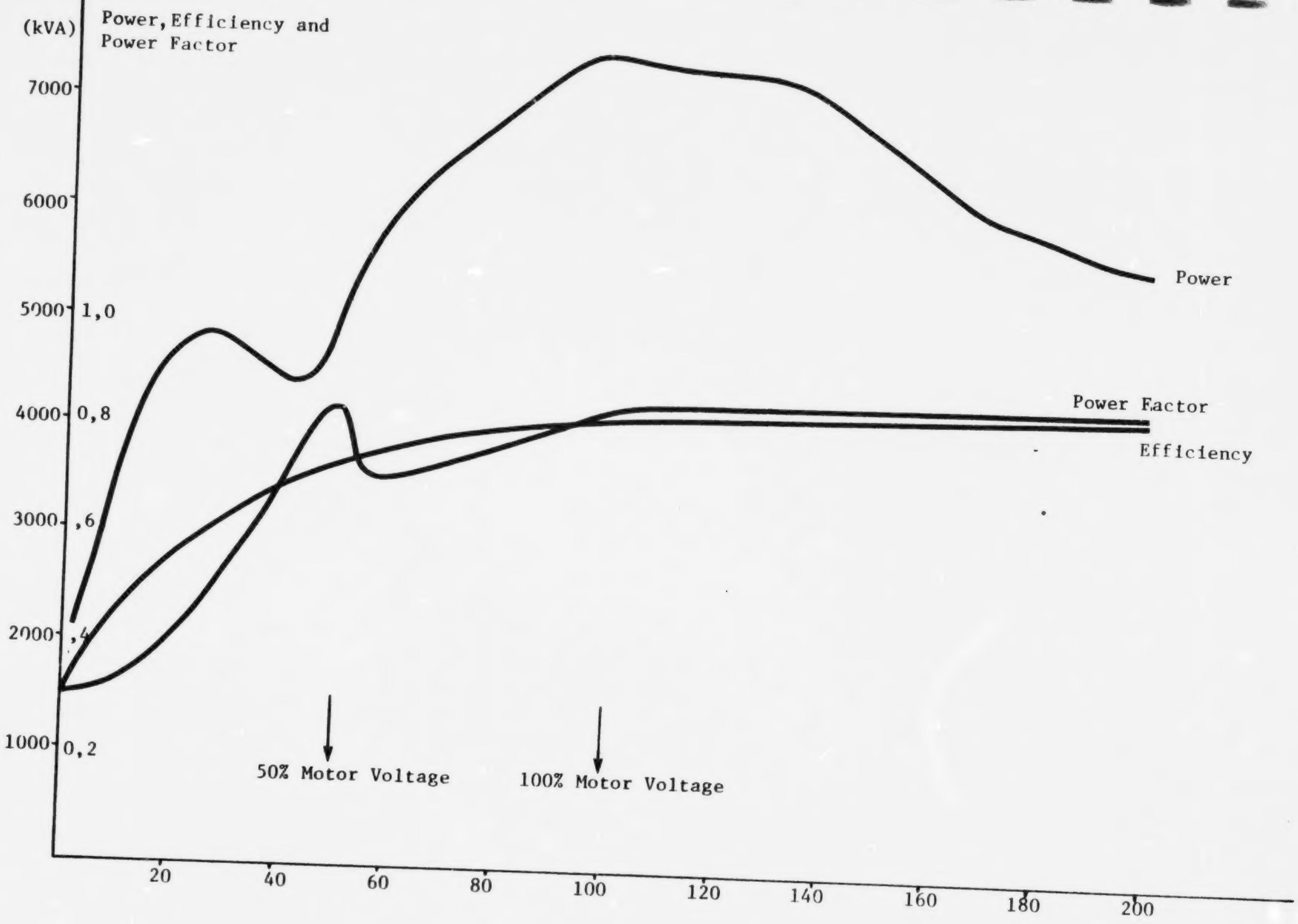


Figure E-4 Power, Efficiency, and Power Factor as a Function of Speed (Dry Level Tangent Track, Five-Car Consist)

E.2.5 Braking Performance

Braking time and distance were calculated based on an average deceleration rate of 0,6 m/s^2. Results are shown in Table E-10 and Figure E-5.

E.2.6 Performance of the Rail Technology

Figure E-6 shows Speed and Distance as a function of Time in the acceleration and braking modes, from 0 to 200 km/h.

E.2.7 Trip Time Calculation

Results of the calculation show that total trip time between Montreal and Ottawa is 68,7 min. Trip times for intermediate point are:

- Montreal - West Island : 7,5 min;
- West Island - Mirabel : 13,8 min;
- Mirabel - Ottawa : 44,5 min;
- Montreal - Mirabel : 22,8 min.

Speed is limited to 160 km/h between Montreal and West Island station due to a 1000 m curve in the Mount Royal tunnel and a 1200 m curve 5,8 km before West Island station.

Also, speed is limited to 120 km/h between the end of the Montreal Island and Deux-Montagnes due to three 600 m curves.

An analysis was also made to establish the impact of speed restrictions due to curves between Montreal and Ottawa. The analysis should that the saving in trip time resulting from straightening the route in order to eliminate those curves would be approximately 2 to 3 minutes.

Table E-10

Performance Characteristics of the Rail Technology (Deceleration)

S (km/h)	a (m/s²)	Δt (s)	t (s)	Δd (m)	d (m)
200			92,6		2 572
	0,60	4,63		250	
190			88,0		2 322
	0,60	4,63		238	
180			83,3		2 084
	0,60	4,63		225	
170			78,7		1 859
	0,60	4,63		212	
160			74,1		1 647
	0,60	4,63		199	
150			69,5		1 448
	0,60	4,63		187	
140			64,8		1 261
	0,60	4,63		174	
130			60,2		1 087
	0,60	4,63		161	
120			55,6		926
	0,60	4,63		148	
110			50,9		778
	0,60	4,63		135	
100			46,3		643
	0,60	4,63		122	
90			41,7		521
	0,60	4,63		109	
80			37,0		412
	0,60	4,63		97	
70			32,4		315
	0,60	4,63		84	
60			27,8		231
	0,60	4,63		71	
50			23,2		160
	0,60	4,63		58	
40			18,5		102
	0,60	4,63		45	
30			13,9		57
	0,60	4,63		32	
20			9,2		25
	0,60	4,63		19	
10			4,6		6
	0,60	4,63		6	
0			0,0		0

Note: Performance is given for a five-car consist on dry level tangent track.

Therefore, considering the cost associated with straightening those curves and the problems and costs resulting from the necessary expropriations, it was not considered warranted to realign the route.

In summary, a total trip time of 70 minutes can be used in the analysis for the Montreal - Mirabel - Ottawa Rail service.

Figure E-7 shows the Speed-Distance relations for the route.

E.2.8 Appraisal of Vehicle Performance Evaluation

Several reservations must be made about the procedure used above for evaluating the Rail vehicle performance, the most important being the lack of specificity in selecting parameters.

The dilemma was the following: either to use the estimated parameters of a given vehicle or to use average parameters corresponding to some extent to several vehicles but in fact to more precisely. As the study is concerned with two technologies, not with two vehicles, the latter course of action was adopted despite its inherent limitation.

As no specific vehicle was contemplated, the use of the Davis formula was acceptable. This formula, dating back to 1934 has been updated over the years and is still being used today in North America to dimension propulsion systems, despite its lack of precision especially in the high speeds. A more precise formula, more sensitive to aerodynamic drag, would naturally be used for system design when a vehicle is selected.

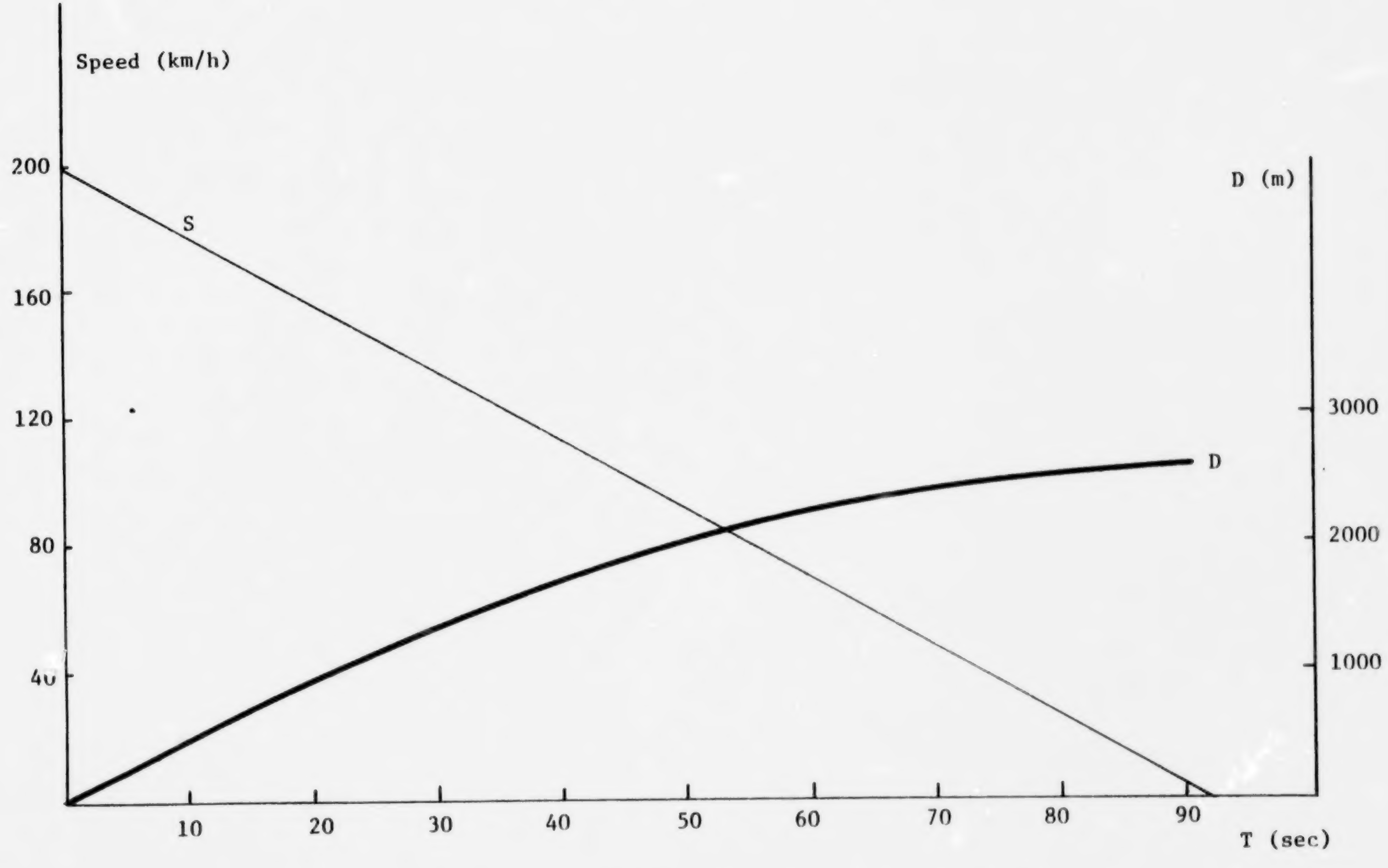


Figure E-5 Speed and Distance as a Function of Time: Normal Service Braking (Dry Level Tangent Track, Five-Car Consist)

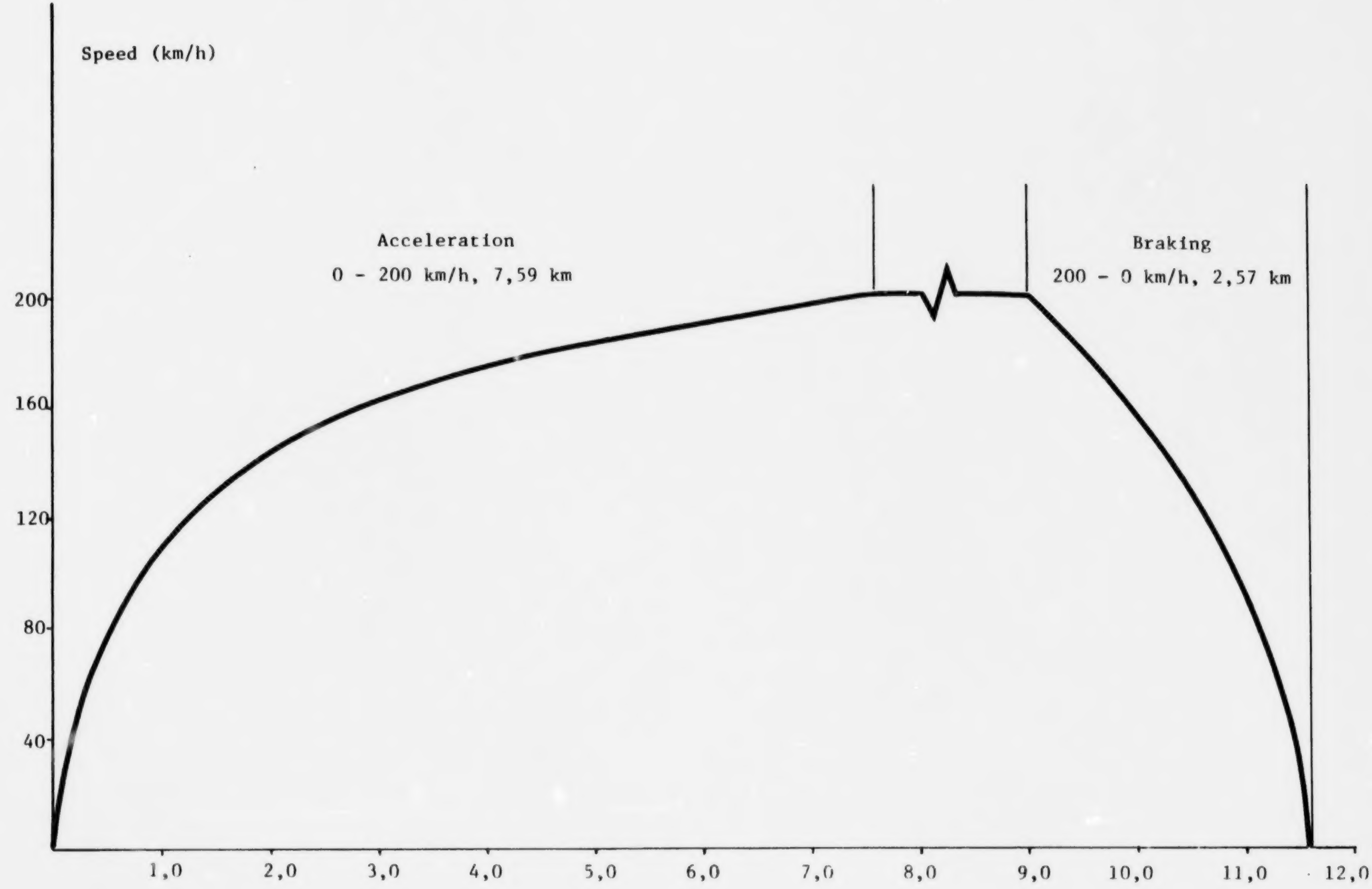


Figure E-6 Speed and Distance as a Function of Time: Acceleration and Braking (Dry Level Tangent Track, Five-Car Consist)

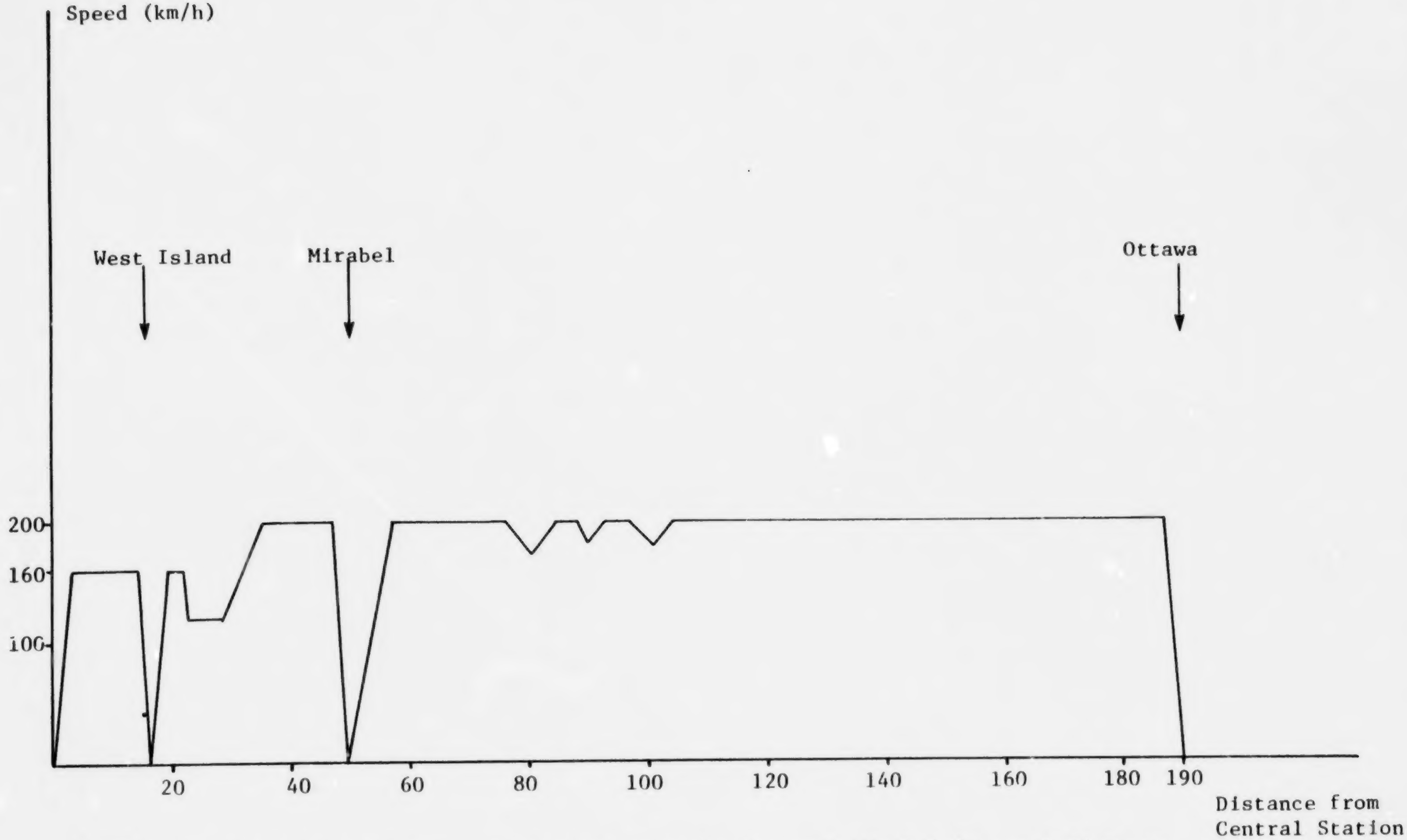


Figure E-7 Speed as a Function of Distance over the Montreal-Mirabel-Ottawa Rail Route (Dry Level Tangent Track, Five-Car Consist)

E.3 Infrastructure

This section of Appendix E corresponds to Section 5.5 in Chapter 5 and provides complementary documentation. It is organized in the same order. However, the only items discussed in the present section are those on which complementary information is necessary.

E.3.1 Track Layout

The track layout adopted for the Rail system definition is shown schematically in Figure E-8. Its principal features and the reasons for their adoption are described below.

The route starts on Tracks 13 and 14 in Central Station; these will be operated as stub tracks with trains departing for and arriving from the Mount Royal Tunnel only.

As the tunnel will not be widened, the Rail system (HSR) will have to share double tracks in the tunnel with other railway traffic; the existing tracks will be rebuilt and resignalled. The necessary switches and crossovers will be provided to ensure that high speed trains coming from (leaving for) any track in the tunnel can enter (leave from) Track 13 or 14 indifferently.

Near the north end of the tunnel, another double crossover will be placed to allow bi-directional single-track operation in the tunnel. In addition, two switches and a diamond crossing will allow the two tunnel tracks to fan out into four tracks: two exclusive HSR tracks on the west side and two exclusive tracks on the east side for future commuter services. This is where starts the HSR's own centralized traffic control, at km 6+100 approximately (Figure E-8, page 1).

Given the frequent HSR and commuter traffic, Eastern Junction will be grade-separated. This is already planned by COTREM as part of the rehabilitation of the Deux-Montagnes commuter service and its transformation into a high-frequency transit-type operation.

From km 7+500 to km 8+200 approximately, there are presently industrial sidings on both sides of the right-of-way. To prevent these operations from interfering with the HSR and/or commuter services, new lead tracks will be built, one on each side of the right-of-way. Beyond Eastern Junction, a new freight track will be built on the west side of the right-of-way to allow freight trains to serve Doney Spur from Taschereau Yard through Mount Royal and Montfort Subdivisions without interfering with HSR and commuter operations.

Around km 11+200, the new freight track on the west side of the right-of-way will be linked to Cartierville Spur on the east side, mainly through a succession of diamond crossings. In addition, a double crossover will allow trains to move back and forth between the new freight track and one HSR track in emergency situations. Furthermore, from km 11+000 to km 11+900 approximately, a second new freight track will be built to serve industries on the east side of the right-of-way; it will be connected to Cartierville Spur.

From km 12+000 to km 12+600, the existing freight siding will be rebuilt on the west side of the right-of-way for manoeuvering freight trains; it will be slightly west of its present location.

From km 12+600 to km 15+700, five new tracks will be built in the right-of-way: two exclusive commuter tracks, two exclusive HSR tracks, and one exclusive CN freight track. Three existing connections to industrial sidings will be rebuilt.

From km 15+700 to km 16+300, a new siding will be built to replace an existing siding; the new siding will, like the present one, provide a connection to Doney Spur.

From km 16+300 to km 28+800, five new tracks will be built. An existing connection to an industrial siding at km 20+700 will be rebuilt. Three existing single-track bridges will be rebuilt to carry the five new tracks (Figure E-8, page 2).

At km 28+800 and at km 30+800, two single crossovers will link the CN track with the enter HSR track. Between these, two other single crossovers will allow movements between the two HSR tracks.

The two new commuter tracks will end at km 31+200, from which point on three new tracks will be built.

Around km 34, the HSR tracks leave the CN right-of-way. Reconstruction of the CN freight track will stop (Figure E-8, page 3).

Around km 38, there will be a level crossing between the CN right-of-way and single track and the two HSR tracks built in a new right-of-way. It will be fully-protected (Figure E-8, page 4).

Around km 44, there will be a junction (called "Mirabel Junction") between the two HSR tracks from Montreal and the two HSR tracks from Ottawa, which will merge into two new tracks to the Mirabel Station. This junction will consist of four single switches and a diamond crossing, supplemented by single crossover at km 46.

The "Mirabel Spur" will terminate with two stub tracks. From Mirabel Junction towards Ottawa, two new tracks will be built, to be used exclusively by HSR trains (Figure E-8, page 5).

The next layout feature is a double crossover at km 73 and a crossing with the now abandoned portion of CN Grenville Spur at km 78 (Figure E-8, page 6). Around km 94, the HSR tracks join the CP M.&O. Subdivision and, in doing so, cross the existing CP track. This level crossing is fully-protected and is followed by a two single crossovers, one at each end of an emergency and maintenance siding, around km 96 (Figure E-8, page 7).

Around km 102, there is a protected level crossing with the single track in the CN Hawkesbury Spur.

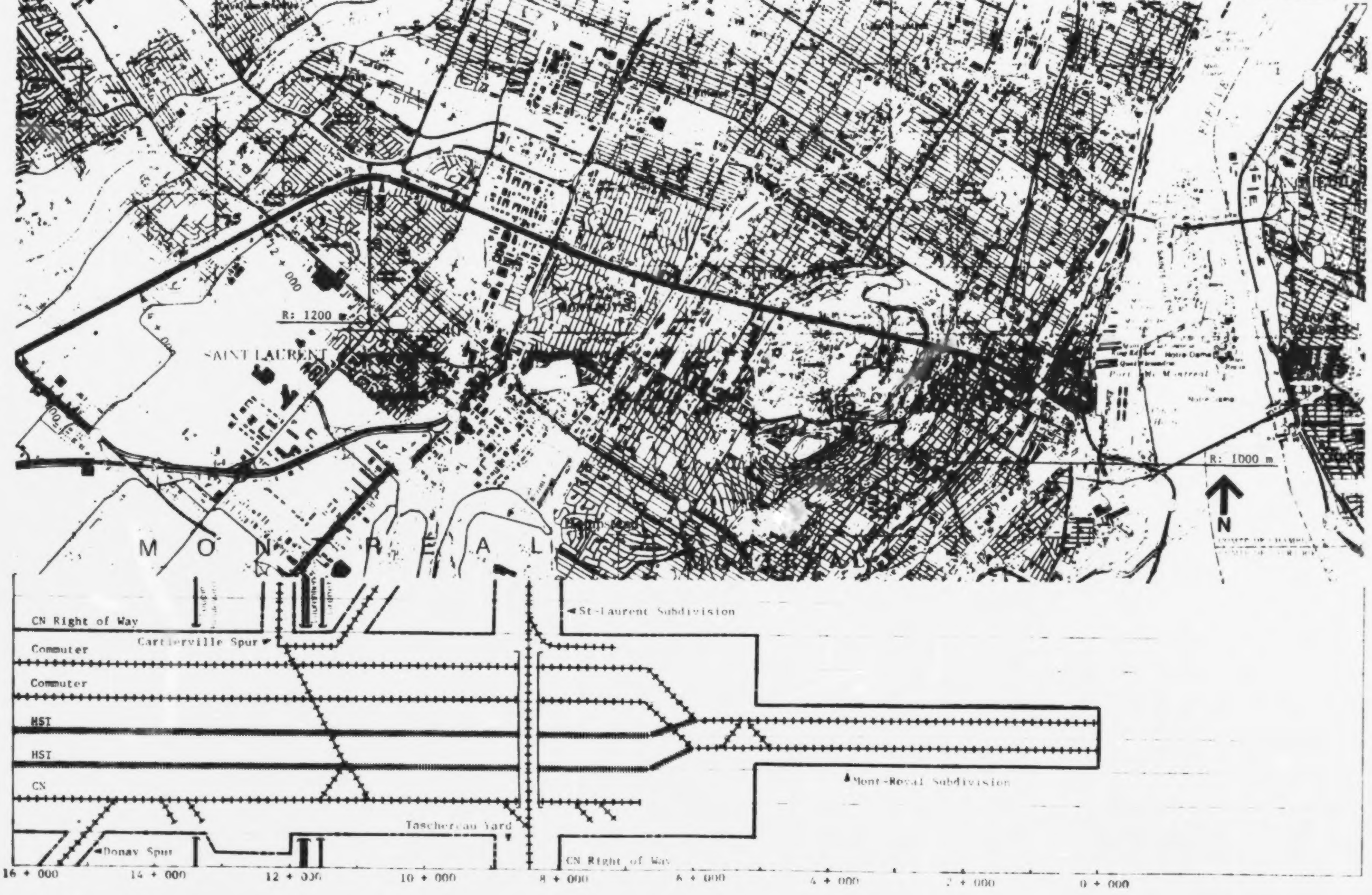
There is no track feature until two double crossovers, at km 118 and at km 139; at this point, there is also an emergency and maintenance siding (Figure E-8, page 9).

From km 95+500 to km 151, the HSR tracks will be built on the south side of the right-of-way. At km 151, the HSR tracks pass from the south side to the north side of the right-of-way. Shortly thereafter, there is a double crossover for movement from one HSR track to the other. Around km 162, another double crossover allows movements between the CP track and the north HSR track (Figure E-8, page 10).

Near Ottawa, there is, at km 184+150, a level crossing with a CN industrial siding: near Ottawa Station, the right-of-way is used jointly by CN and CP. Beyond that level crossing, just before the station, a double crossover allows movements between the HSR tracks, which terminate as a stub terminal. Slightly beyond the station, enough space is left to store two trains on each track (Figure E-8, page 11).

The number of tracks at various points along the route from Montreal to Ottawa is shown in Table E-11. The route has a total length of 185 km (although, due to the switchbacks at Mirabel, trains will travel 190 km). On all of this route, a new double track of 185 km will be built, to be used exclusively for the HSR service for 179,6 km. In addition, there will be 25,8 km of exclusive double track for commuter services, 29,3 km of exclusive freight track, built double for 3,1 km and single for 23,1 km.

FIGURE E-8 TRACK LAYOUT FOR RAIL (PAGE 1 11)



SAINT LAURENT
R: 1200 m
12 + 000
R: 1000 m
N
M O N T R É A L
CN Right of Way
Commuter
Cartierville Spur
Commuter
HST
HST
CN
Donay Spur
Taschereau Yard
St-Laurent Subdivision
Mont-Royal Subdivision
CN Right of Way
16 + 000
14 + 000
12 + 000
10 + 000
8 + 000
6 + 000
4 + 000
2 + 000
0 + 000

FIGURE E-8 TRACK LAYOUT FOR RAIL (PAGE 2/11)

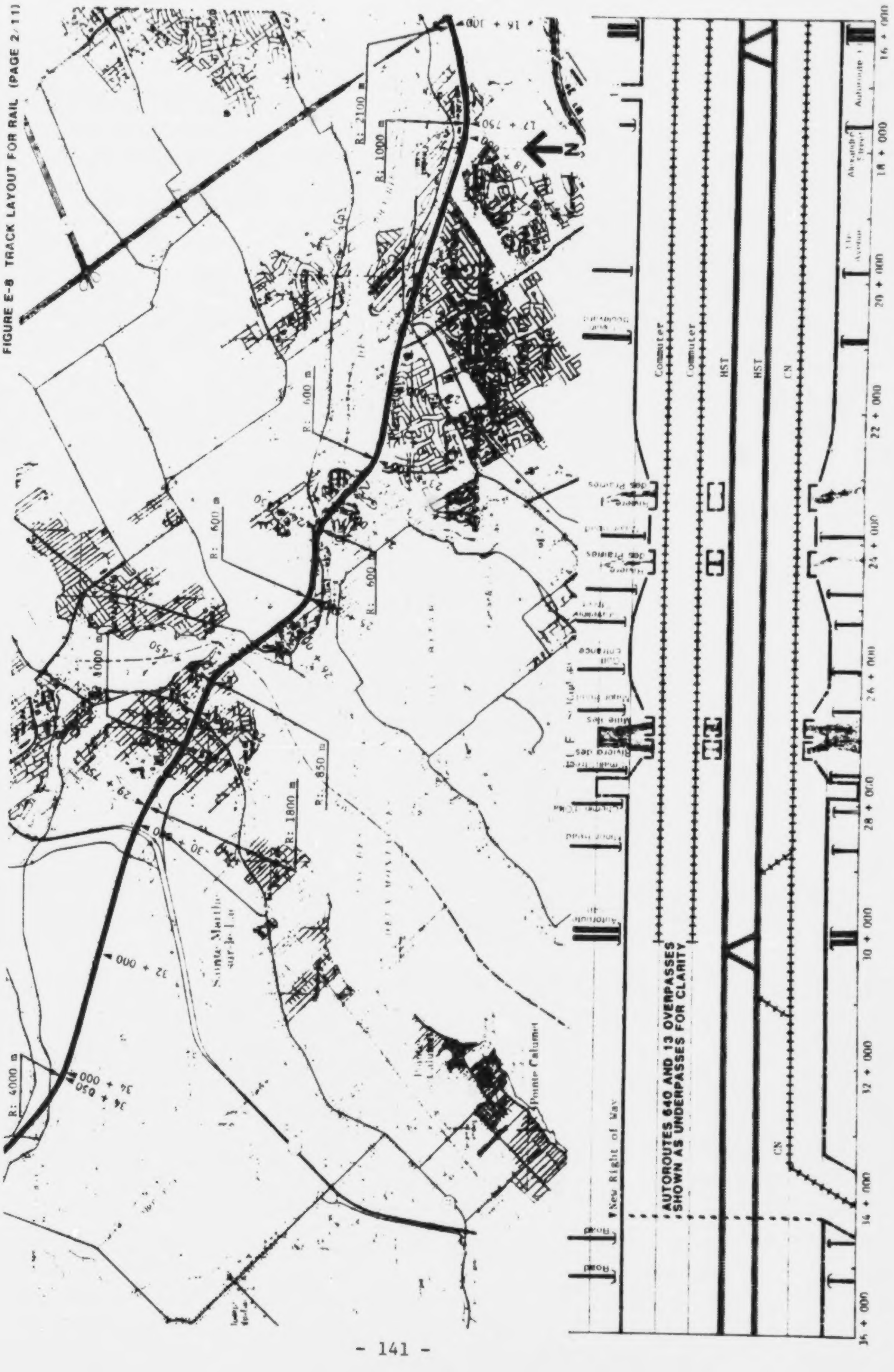

R: 2100 m
R: 1000 m
R: 600 m
R: 600 m
R: 600 m
R: 1000 m
R: 850 m
R: 1800 m
R: 4000 m
16 + 000
17 + 750
18 + 000
26 + 000
29 + 750
30 + 000
32 + 000
34 + 000
34 + 050
N
Sainte-Marthe-sur-le-Lac
Pointe Calumet
New Right of Way
AUTOROUTES 640 AND 13 OVERPASSES SHOWN AS UNDERPASSES FOR CLARITY
Commuter
Commuter
HST
HST
CN
CN
Road
Road
Autoroute 640
Golf entrance
Autoroute 13
Alexandre Street
36 + 000
34 + 000
32 + 000
30 + 000
28 + 000
26 + 000
24 + 000
22 + 000
20 + 000
18 + 000
16 + 000

FIGURE E-8 TRACK LAYOUT FOR RAIL (PAGE 3/11)

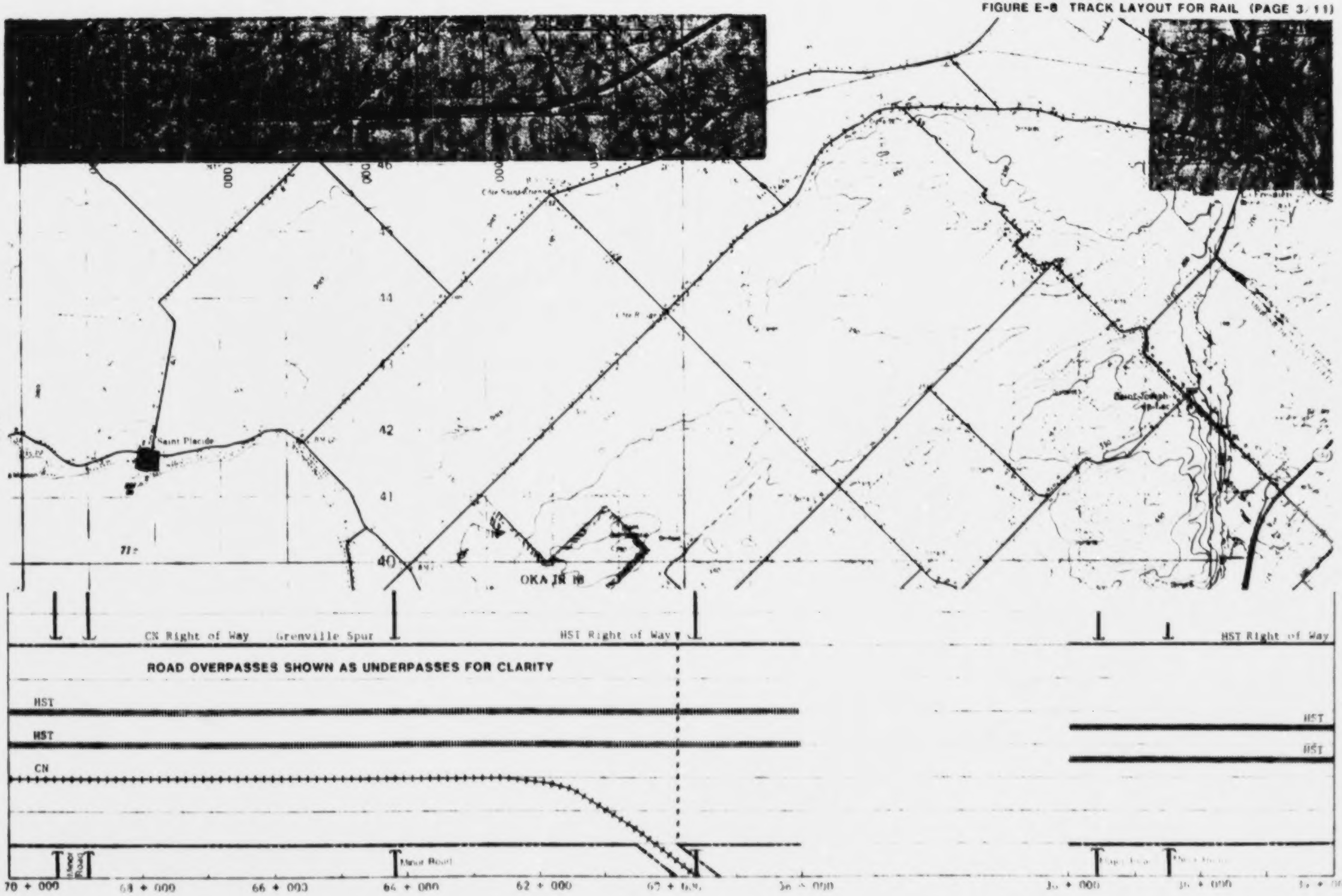
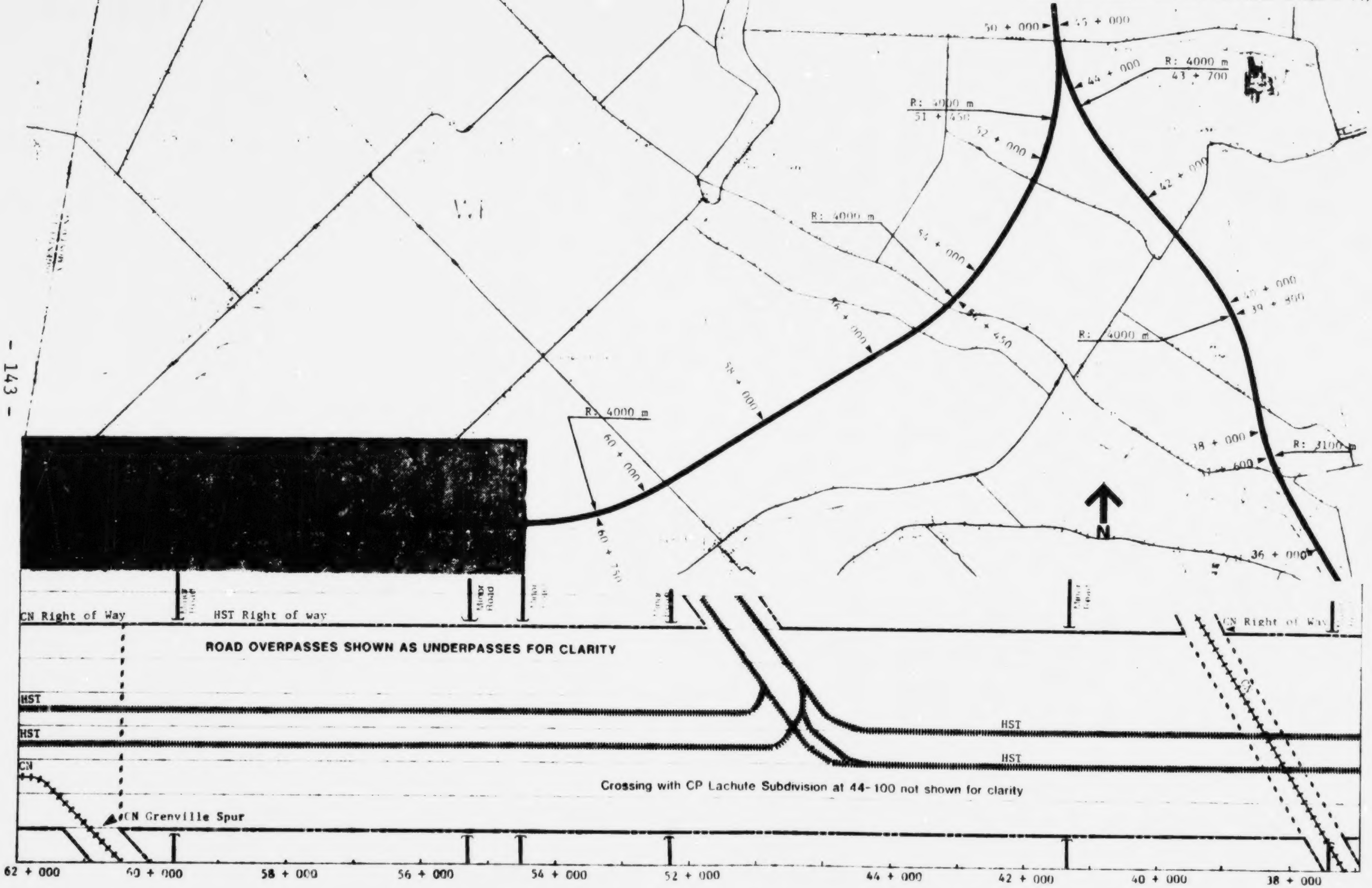

Saint Placide
42
41
40
44
46
OKA IR 18
Saint-Joseph-du-Lac
CN Right of Way
Grenville Spur
HST Right of Way
HST Right of Way
ROAD OVERPASSES SHOWN AS UNDERPASSES FOR CLARITY
HST
HST
CN
HST
HST
Minor Road
70 + 000
68 + 000
66 + 000
64 + 000
62 + 000

FIGURE E-8 TRACK LAYOUT FOR RAIL (PAGE 4 11)


50 + 000
45 + 000
44 + 000
R: 4000 m
43 + 700
R: 4000 m
51 + 450
52 + 000
42 + 000
R: 4000 m
54 + 000
54 + 450
56 + 000
40 + 000
39 + 800
R: 4000 m
58 + 000
R: 4000 m
60 + 000
60 + 750
38 + 000
37 + 600
R: 3100 m
36 + 000
N
Minor Road
CN Right of Way
HST Right of way
CN Right of Way
HST
HST
HST
HST
CN
CN Grenville Spur
62 + 000
60 + 000
58 + 000
56 + 000
54 + 000
52 + 000
44 + 000
42 + 000
40 + 000
38 + 000

[redacted]

ROAD OVERPASSES SHOWN AS UNDERPASSES FOR CLARITY

Crossing with CP Lachute Subdivision at 44-100 not shown for clarity

FIGURE E-8 TRACK LAYOUT FOR RAIL (PAGE 5/11)

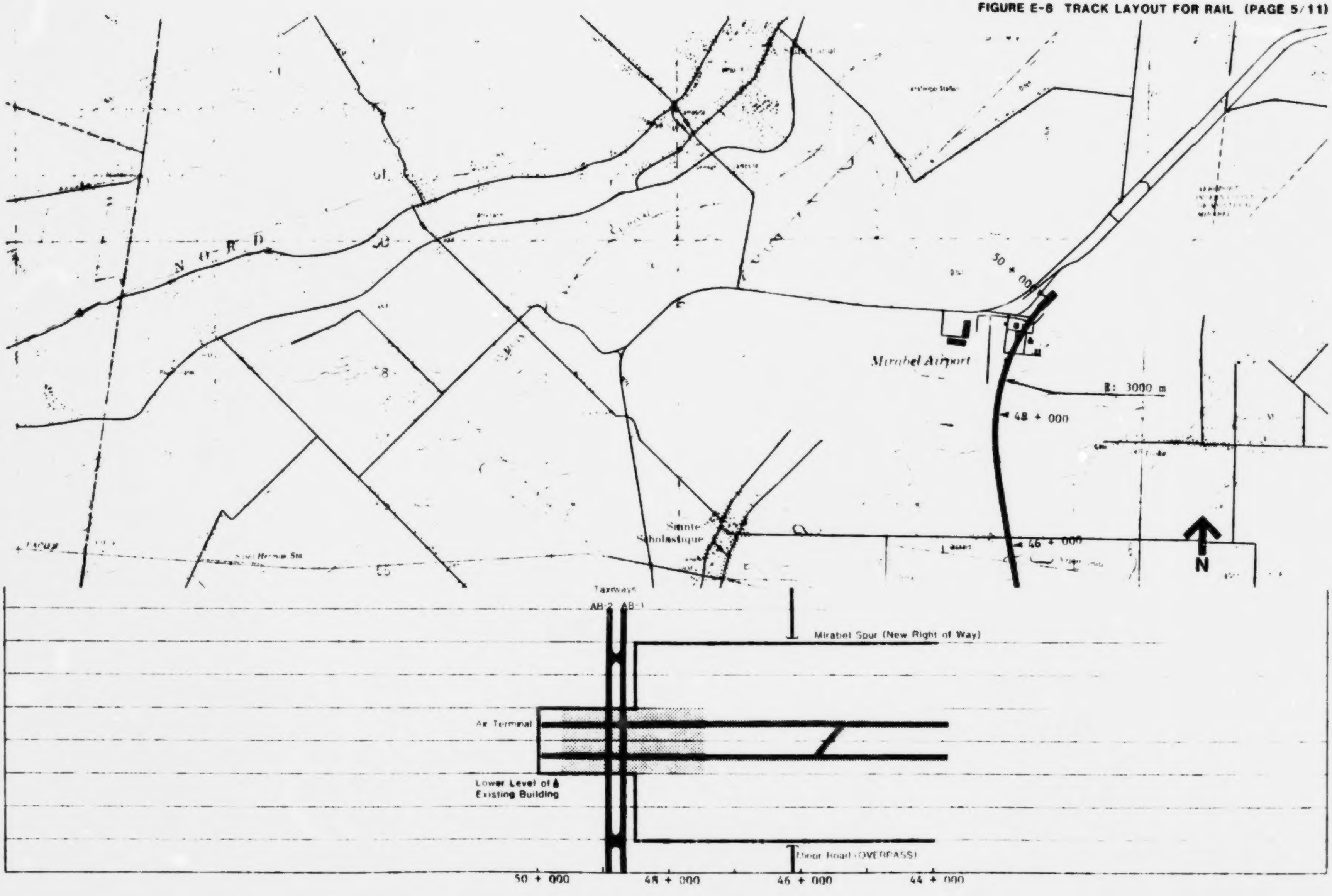

50 + 000
Mirabel Airport
R: 3000 m
48 + 000
46 + 000
N O R D
Sainte-Scholastique
N
Taxiways
AB-2 AB-1
Mirabel Spur (New Right of Way)
Air Terminal
Lower Level of ℄ Existing Building
Major Road (OVERPASS)
50 + 000
48 + 000
46 + 000
44 + 000

FIGURE E-8 TRACK LAYOUT FOR RAIL (PAGE 6/11)

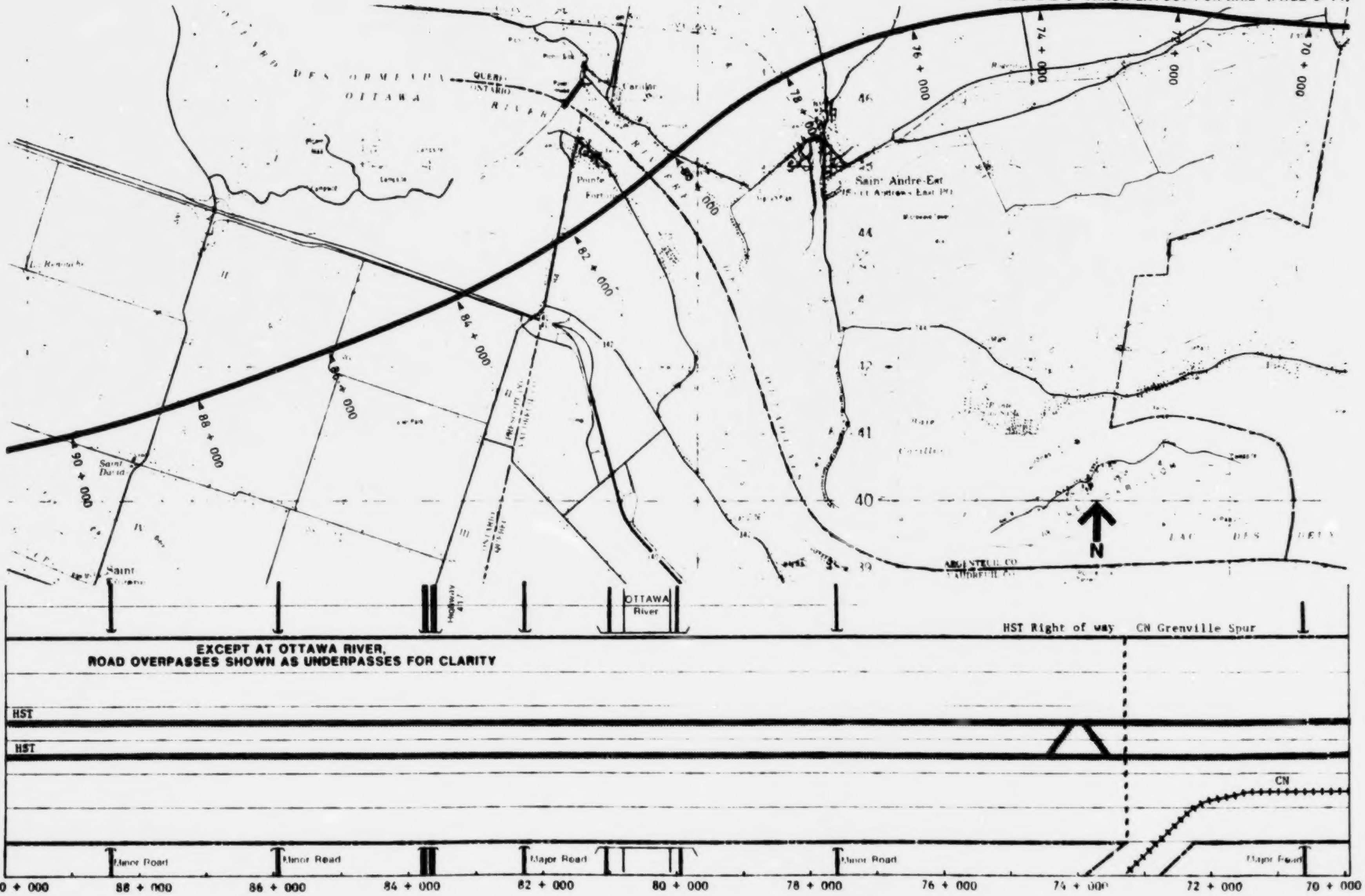

70 + 000
72 + 000
74 + 000
76 + 000
78 + 000
80 + 000
82 + 000
84 + 000
86 + 000
88 + 000
90 + 000
Saint-André-Est
Pointe Fortune
Carillon
QUEBEC
ONTARIO
OTTAWA RIVER
Saint David
LAC DES DEUX
N
OTTAWA River
Highway 417
HST Right of way
CN Grenville Spur
EXCEPT AT OTTAWA RIVER,
ROAD OVERPASSES SHOWN AS UNDERPASSES FOR CLARITY
HST
HST
CN
Minor Road
Minor Road
Major Road
Minor Road
Major Road
90 + 000
88 + 000
86 + 000
84 + 000
82 + 000
80 + 000
78 + 000
76 + 000
74 + 000
72 + 000
70 + 000

FIGURE E-8 TRACK LAYOUT FOR RAIL (PAGE 7/11)

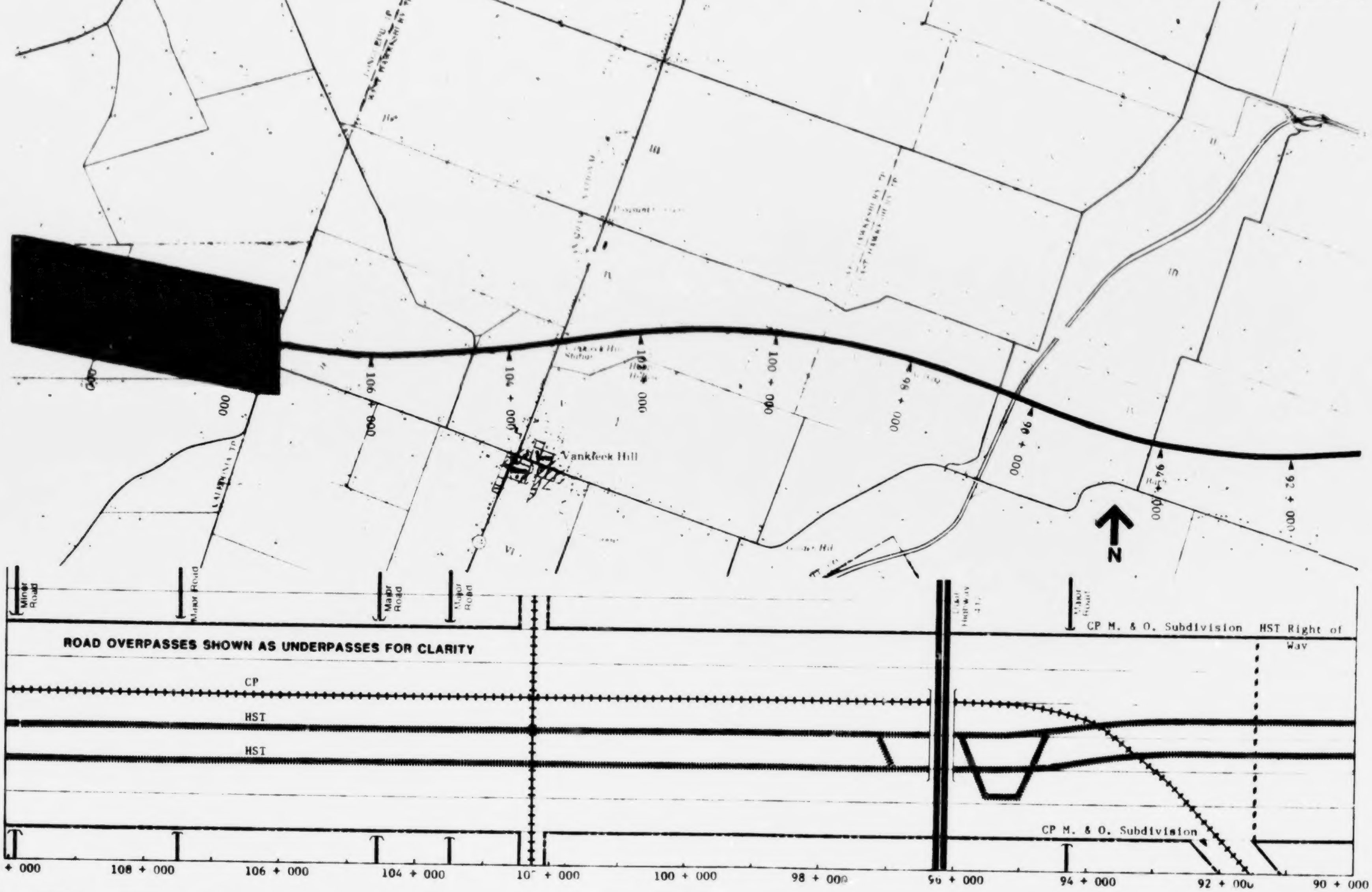

92 + 000
94 + 000
96 + 000
98 + 000
100 + 000
102 + 000
104 + 000
106 + 000
000
000
N
Vankleek Hill
Minor Road
Major Road
Major Road
Major Road
Major Road
Highway 417
CP M. & O. Subdivision
HST Right of Way
ROAD OVERPASSES SHOWN AS UNDERPASSES FOR CLARITY
CP
HST
HST
CP M. & O. Subdivision
110 + 000
108 + 000
106 + 000
104 + 000
102 + 000
100 + 000
98 + 000
96 + 000
94 + 000
92 + 000
90 + 000

FIGURE E-8 TRACK LAYOUT FOR RAIL (PAGE 8/11)

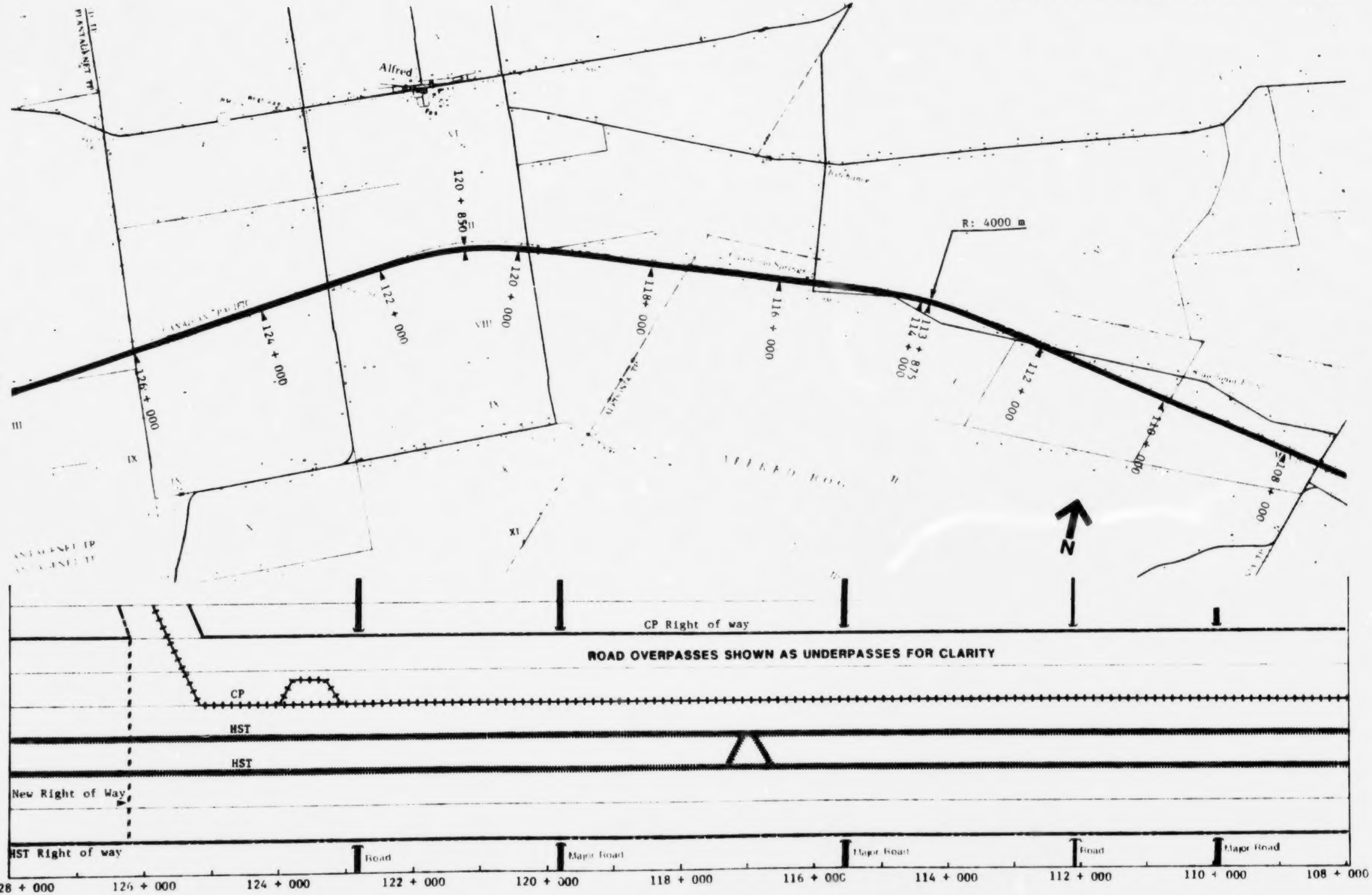
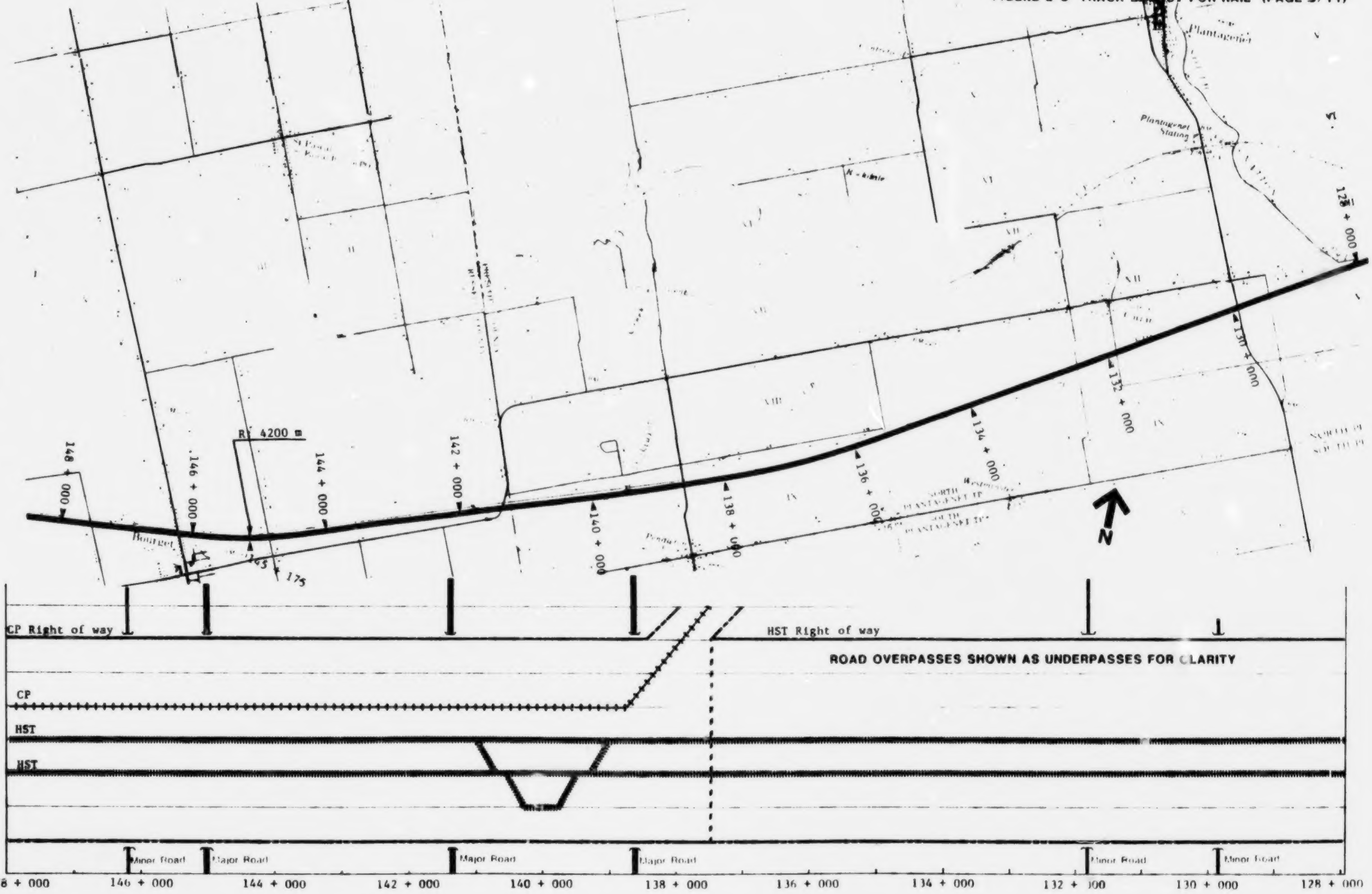

Alfred
Plantagenet Tp
R: 4000 m
108 + 000
110 + 000
112 + 000
113 + 875
114 + 000
116 + 000
118+ 000
120 + 000
120 + 850
122 + 000
124 + 000
126 + 000
N
CP Right of way
ROAD OVERPASSES SHOWN AS UNDERPASSES FOR CLARITY
CP
HST
HST
New Right of Way
HST Right of way
Road
Major Road
Major Road
Road
Major Road
128 + 000
126 + 000
124 + 000
122 + 000
120 + 000
118 + 000
116 + 000
114 + 000
112 + 000
110 + 000
108 + 000

FIGURE E-8 TRACK LAYOUT FOR RAIL (PAGE 9/11)


Plantagenet
Plantagenet Station
128 + 000
130 + 000
132 + 000
134 + 000
136 + 000
138 + 000
140 + 000
142 + 000
144 + 000
146 + 000
148 + 000
N
R 4200 m
175
Bourget
NORTH PLANTAGENET TP
SOUTH PLANTAGENET TP
HST Right of way
CP Right of way
CP
HST
HST
Minor Road
Major Road
Major Road
Major Road
Minor Road
Minor Road
148 + 000
146 + 000
144 + 000
142 + 000
140 + 000
138 + 000
136 + 000
134 + 000
132 + 000
130 + 000
128 + 000

ROAD OVERPASSES SHOWN AS UNDERPASSES FOR CLARITY

FIGURE E-8 TRACK LAYOUT FOR RAIL (PAGE 10/11)

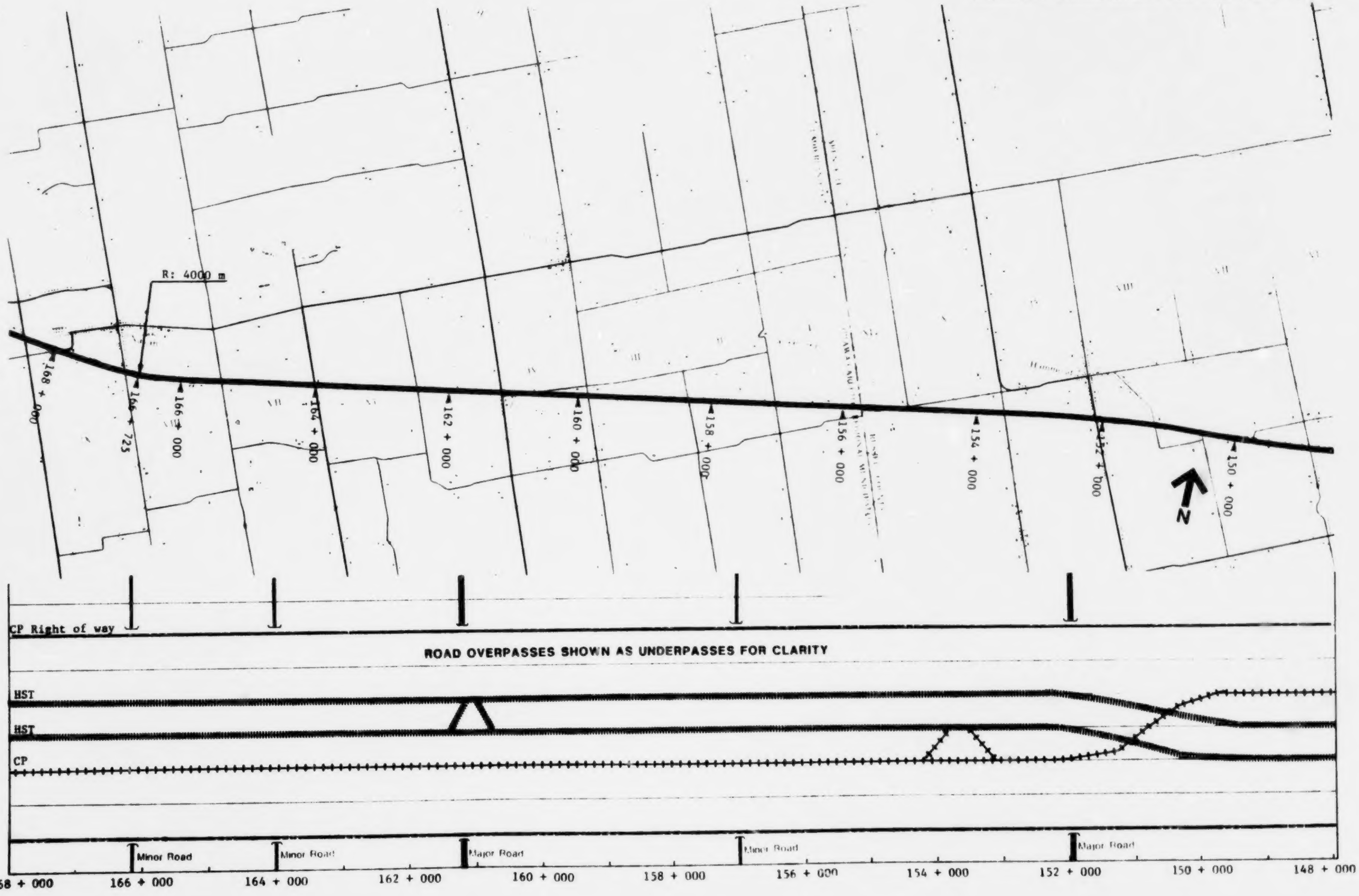
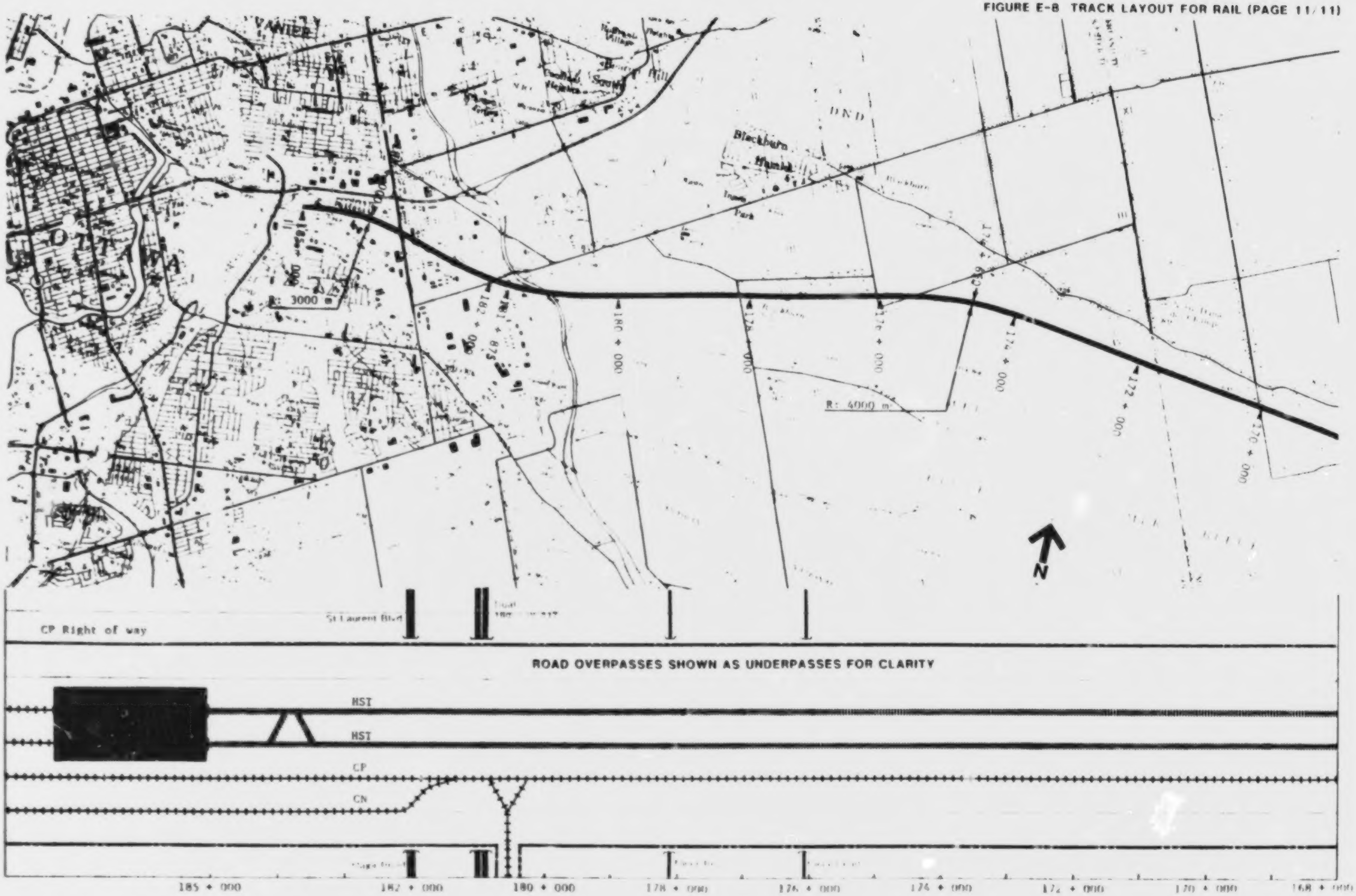

150 + 000
152 + 000
154 + 000
156 + 000
158 + 000
160 + 000
162 + 000
164 + 000
166 + 000
166 + 725
168 + 000
N
R: 4000 m
CP Right of way
ROAD OVERPASSES SHOWN AS UNDERPASSES FOR CLARITY
HST
HST
CP
Minor Road
Minor Road
Major Road
Minor Road
Major Road
168 + 000
166 + 000
164 + 000
162 + 000
160 + 000
158 + 000
156 + 000
154 + 000
152 + 000
150 + 000
148 + 000

FIGURE E-8 TRACK LAYOUT FOR RAIL (PAGE 11/11)


VANIER
OTTAWA
Blackburn Hamlet
DND
R: 3000
R: 4000 m
180 + 000
178 + 000
176 + 000
174 + 650
174 + 000
172 + 000
170 + 000
181 + 875
182 + 000
185 + 000
N
CP Right of way
St Laurent Blvd
ROAD OVERPASSES SHOWN AS UNDERPASSES FOR CLARITY
HST
HST
CP
CN
185 + 000
182 + 000
180 + 000
178 + 000
176 + 000
174 + 000
172 + 000
170 + 000
168 + 000

E.3.2 Right-of-Way

The detailed right-of-way requirements are shown in Table E-12, which is summarized in Table 5-1.

Table E-12 also shows the number and location of buildings that must be expropriated and relocated or demolished, as well as the area of woodland that must be cleared, for the acquisition of the necessary right-of-way.

E.3.3 Soil Conditions along the Route

This sub-section provides background information for Sub-section 5.5.5.

The "qualification" of soils found at any point along the route into one of the four given levels of quality described in 5.5.5 was done, based on their materials and type, as found on geological maps. The result is shown in Table E-13.

Based on the qualification process resulting in Table E-13, the distribution of soils into the four quality levels, as a function of their location along the route, is given in Table E-14, together with the cumulative length of each type.

E.3.4 Quantity Estimation for Trackwork

The quantities of excavation and fill for roadbed, sub-ballast, and ballast, were estimated, with the usual engineering techniques, based on the following data.

- the alignment and profile of the Rail route as shown on the maps of Appendix C;

- the terrain profile shown on the same maps;
- the type of soil at each location as given in Table E-14;
- the width of the right-of-way and the number and type of tracks.

The result of the estimation is shown in Table E-15. Quantities were compiled by location and according to whether the work was needed for HSR tracks, for commuter tracks, or for rebuilding (and sometimes relocating as well) existing freight tracks.

A brief explanation of the nature of items appearing in that table follows.

The "Rock Excavation" category groups all work done within the right-of-way to obtain the necessary roadbed profile when rock excavation is necessary; the appropriate unit cost in $\$30/m^3$.

The "Rock Tunneling" category applies when excavation in a tunnel is necessary. The appropriate unit cost is $\$50/m^3$ and includes no provision for concreting the tunnel.

The "Topsoil Removal" category, priced at $\$2/m^3$, presumes an average topsoil thickness of 300 mm in the right-of-way.

"Soil Excavation" (also known as second class excavation) includes all grading work for cuts within the limits of the right-of-way, except for rock excavation. The quantities were estimated based on the track profile in Appendix D and the right-of-way width in Table 5-1; the unit cost is $\$2/m^3$.

"Borrowed Material" (known as Class B) where grading within the right-of-way does not yield sufficient material of an acceptable quality for the track roadbed or track foundation. The material must then be borrowed from outside the right-of-way. The unit cost of $\$7/m^3$ includes provisions for transportation, placement, and compaction to the specifications.

"Ballast" will be laid in a 300 mm thick layer according to Figure 5-4. The unit cost is estimated at \$15/m^3 (in place) and the quantity required is a function of the length of single track.

"Sub-Ballast" thickness will vary with local sub-soil conditions as shown in Figure 5-4 and the quantity was estimated based on data in Table E-14. The unit price is \$15/m^3 in place.

"Road Foundation" is required for road reconstruction near new and rebuilt grade separations. An average thickness if 700 mm is assumed. The quantity was estimated based on the number and types of grade separations (Table E-17). The unit price is estimated at \$15/m^3 in place. "Asphalt for Roadwork" is a layer of 80 mm at the approaches of grade separations.

E.3.5 Quantity Estimation for Turnouts

By way of complement to Sub-section 5.5.6, and based on the track layout shown in Figure E-8. Table E-16 shows the type and location of turnouts required for the Rail system.

Table E-11

Number of Tracks in the Right-of-Way

Map	Track Usage	Kilometric Points From	Kilometric Points To	Length (m)	New Track Construction HSR	New Track Construction Commuter	New Track Construction Freight	Existing Tracks	Total Tracks in Right-or-Way
2	S	0 000	5 400	5 400	2	2	-	2R	2
2	E	5 400	7 600	2 200	2	2	-	2R	4
2	E	7 600	8 600	1 000	2	2	2	2R	6
2	E	8 600	11 300	2 700	2	2	1	2R	5
2	E	11 300	12 600	1 300	2	2	2	2R	6
2	E	12 600	15 700	3 100	2	2	1	1R	5
2	E	15 700	16 300	600	2	2	2	1R	6
3	E	16 300	31 200	14 900	2	2	1	1R	5
3	E	31 200	33 600	2 400	2	-	1	1	3
3	N	33 600	35 600	2 000	2	-	-	-	2
4	N	35 600	37 300	1 700	2	-	-	-	2
4	E	37 300	39 500	2 200	2	-	-	1R	3
4	N	39 500	45 000	5 500	2	-	-	-	2
5	N	45 000	50 000	5 000	2	-	-	-	2
4	N	50 000	62 000	12 000	2	-	-	-	2
4	E	62 000	70 000	8 000	2	-	-	1R	3
6	N	70 000	90 000	20 000	2	-	-	-	2
7	N	90 000	95 500	5 500	2	-	-	-	2
7	E	95 500	108 000	12 500	2	-	-	1	3
8	E	108 000	125 500	17 500	2	-	-	1	3
9	N	125 500	138 500	13 000	2	-	-	-	2
9	E	138 500	148 500	10 000	2	-	-	1R	3
10	E	148 500	169 000	20 500	2	-	-	1R	3
11	E	169 000	185 000	16 000	2	-	-	1R	3
Total Length (Hm)				1 850	1 850	312	260		
Shared					54	54	-		
Exclusive					1 796	258	231 (1) 29 (2)		

Notes: S: Shared tracks.
T: Tunnel.
E: Exclusive tracks in rented right-of-way.
R: Rebuilt on site or relocated.

Table E-13

Soil Qualification as a Function of Soil Type

Soil Materials	Soil Type	Soil Quality
Silty clay, silt clayey silt	A1 - A2	S1 Not to be used for roadbed
Marine, clay, soft to firm clay	A3 - A4	S1 Not to be used for roadbed
Sand with some silt, silty sand	B1	S1
Sand and gravel with silt	B3	S2
Ordinary till	C1	S2
Sandy till	C2	S2 - S3
Rocky till	C3	S2 - S3
Fine to medium sand	D1	S2
Rock	R1	S3
Peat, organic soil, humus, etc.	F	So (to be removed)

Table E-12

Right-of-Way Acquisition Requirements by Location

(Page 1 of 2)

Map	Location (Km at)		City or Location	Existing Right-of-way	Right-of-way Requirement			Number of Buildings	Woodland	
	Beginning	End			Length (m)	Width (m)	Area (ha)		Length (m)	Area (ha)
2	0 000	5 400	Tunnel	CN	5400	--	00,000	-	-	-
2	5 400	7 300	Mont-Royal	CN	1900	15	2,850	-	-	-
2	7 300	10 000	St-Laurent	CN	2700	15	4,050	-	-	-
2	10 000	11 800	Montreal	CN	1800	15	2,700	-	-	-
2	11 800	13 700	St-Laurent	CN	1900	15	2,850	-	-	-
2	13 700	15 700	Montreal	CN	2000	15	3,000	-	-	-
2	15 700	15 825	Montreal	CN	125	15	0,188	-	-	-
2	15 700	15 825	Montreal	Priv.	125	5	0,063	-	-	-
2	15 825	16 200	Pierrefonds	CN	375	15	0,563	-	-	-
2	15 825	16 200	Pierrefonds	Priv.	375	5	0,188	-	-	-
3	16 200	18 950	Pierrefonds	CN	2750	15	4,125	-	-	-
3	18 950	20 200	Roxboro	CN	1250	15	1,875	-	-	-
3	20 200	20 600	Pierrefonds	CN	400	15	0,600	-	-	-
3	20 600	21 100	Roxboro	CN	500	15	0,750	-	-	-
3	21 100	23 350	Pierrefonds	CN	2250	15	3,375	-	-	-
3	23 350	23 550	Riv. des Prairies	Pub.	200	-	-	-	-	-
3	23 550	24 250	Laval	CN	700	15	1,050	-	-	-
3	24 250	24 370	Riv. des Prairies	Pub.	120	-	-	-	-	-
3	24 370	26 800	Laval	CN	2430	15	3,645	-	-	-
3	26 800	26 920	Riv. Mille-Iles	Pub.	120	-	-	-	-	-
3	26 920	26 950	Island	CN	30	15	0,045	-	-	-
3	26 950	27 150	Riv. Mille-Iles	Pub.	200	-	-	-	-	-
3	27 150	29 900	Deux-Montagnes	CN	2750	15	4,125	-	-	-
3	29 900	33 600	St-Eustache	CN	3700	15	5,550	-	-	-
3	33 600	36 400	St-Eustache	Priv.	2800	30	8,400	5	750	2,250
4	36 400	37 200	Mirabel	Priv.	800	30	2,400	-	250	0,750
4	37 200	39 800	Mirabel	CN	2600	15	3,900	-	-	-
4	39 800	43 500	Mirabel	Priv.	3700	30	11,100	-	550	1,650
4	43 500	45 000	Mirabel	Priv.	1500	50	7,500	-	350	1,750
4	45 000	45 750	Mirabel	Priv.	750	50	3,750	-	650	3,250
5	45 750	50 000	Mirabel Airport	TC	4250	50	21,250	-	350	1,750
4	50 000	52 500	Mirabel	Priv.	2500	50	12,500	1	950	4,750
4	52 500	62 000	Rural	Priv.	9500	30	28,500	4	1750	5,250
4	62 000	70 000	Rural	CN	8000	15	12,000	-	-	-

.../.

./...

Table E-12

Right-of-way Acquisition Requirements by Location

(Page 2 of 2)

Map	Location (Km at)		City or Location	Existing Right-of-way	Right-of-way Requirement			Number of Buildings	Woodland	
	Beginning	End			Length (m)	Width (m)	Area (ha)		Length (m)	Area (ha)
6	70 000	76 000	Rural	Priv.	6000	30	18,000	-	1900	5,700
6	76 000	80 100	Rural	Priv.	4100	50	20,500	2	1200	6,000
6	80 100	80 825	Ottawa River	Pub.	725	-	-	-	-	-
6	80 825	82 000	Rural Ontario	Priv.	1175	50	5,875	-	200	1,000
6	82 000	90 000	Rural	Priv.	8000	30	24,000	-	5150	15,450
7	90 000	96 000	Rural	Priv.	6000	30	18,000	-	900	2,700
7	96 000	108 000	Rural	?	12000	?	?	-	3800	?
8	108 000	125 500	Rural	CP	17500	15	26,250	2	-	-
8	125 500	128 000	Rural	Priv.	2500	30	7,500	-	-	-
9	128 000	138 600	Rural	Priv.	10600	30	31,800	1	2550	7,650
9	138 600	148 600	Rural	CP	10000	15	15,000	2	-	-
10	148 600	151 250	Rural	CP	2650	15	3,975	-	-	-
10	151 250	168 500	Rural	CP	17250	15	25,875	3	-	-
11	168 500	171 500	Rural	CP	3000	15	4,500	-	-	-
11	171 500	180 650	Suburban	CP	9150	15	13,725	-	-	-
11	180 650	185 000	Ottawa	CP*	4350	15	6,525	-	-	-

* Joint with CN near Ottawa Terminal.

Table E-14

Soil Quality as a Function of Location along the Rail Route

(Page 1 of 2)

Location, Kilometric Point		Length (m)	Soil Type	Soil Quality	Cumulative Length (m)	Note
From Km	To Km					
0 000	6 050	6 050	R1	S3	6 050	Tunnel
6 050	7 200	1 150	A1 - A2	S1	1 150	-
7 200	8 200	1 000	C1	S2	1 000	-
8 200	9 200	1 000	F	So	1 000	-
9 200	10 100	900	C1	S2	1 900	-
10 100	10 900	800	F	So	1 800	-
10 900	11 500	600	A1 - A2	S1	1 750	-
11 500	12 800	1 300	A3 - A4	S1	3 050	-
12 800	13 700	900	R1	S3	6 950	-
13 700	15 000	1 300	A1 - A2	S1	4 350	-
15 000	30 500	15 500	C1	S2	17 400	Three bridges: (640 m)
30 500	33 400	2 900	A3 - A4	S1	7 250	-
33 400	34 500	1 100	C2 - C3	S3	8 050	-
34 500	42 500	8 000	A3 - A4	S1	15 250	6 m fill on clay
42 500	43 600	1 100	C1	S2	18 500	-
43 600	49 600	6 000	R1	S3	14 050	Possibility of Tunnel
49 600	50 000	400	R1 or C1	S3	14 450	Tunnel or open cut
50 000	52 300	2 300	R1	S3	16 750	Tunnel
52 300	54 000	1 700	C1	S2	20 200	-
54 000	54 600	600	A3 - A4	S1	15 850	-
54 600	56 100	1 500	B1 - C1	S1	17 350	-
56 100	62 000	5 900	A3 - A4	S1	2 350	58 000-5m cut in clay
62 000	63 500	3 500	C2	S2 - S3	-	-
63 500	71 400	7 900	A3 - A4	S1	31 150	68 000-6m fill on clay
71 400	72 400	1 000	B1 - C1	S1	32 150	-
72 400	74 000	1 600	A3 - A4	S1	33 750	-
74 000	76 000	2 000	D1	S2	23 950	-
76 000	87 300	11 300	C2	S2	35 250	Bridge on Ottawa River
87 300	88 500	1 200	A3 - A4	S1	34 950	-
88 500	89 000	500	D1	S2	35 750	-
89 000	89 500	500	A3 - A4	S1	35 450	-
89 500	89 800	300	D1	S2	36 050	-
89 800	94 300	4 500	A3 - A4	S1	39 950	-
94 300	98 000	3 700	C3	S3	22 200	-
98 000	102 700	4 700	A3 - A4	S1	44 650	-
102 700	106 000	3 300	C3	S3	25 500	-

.../.

Table E-14

Soil Quality as a Function of Location along the Rail Route

(Page 2 of 2)

Location Kilometric Point		Length (m)	Soil Type	Soil Quality	Cumulative Length (m)	Note
From Km	To Km					
106 000	107 300	1 300	D1	S2	37 350	-
107 300	109 400	2 100	C3	S3	27 600	-
109 400	110 000	600	A3 - A4	S1	45 250	-
110 000	110 800	800	C3	S3	28 400	-
110 800	111 800	1 000	A1 - A2	S1	46 250	-
111 800	113 000	1 200	C3	S3	29 600	-
113 000	114 000	1 000	F	So	2 800	Replacement over 1 to 2m
114 000	120 000	6 000	A3 - A4	S1	52 250	-
120 000	122 000	2 000	F	So	4 800	Replacement over 1 to 2m
122 000	123 600	1 600	A3 - A4	S1	53 850	-
123 600	124 700	1 100	F	So	5 900	Replacement over 1 to 2m
124 700	131 000	6 300	A3 - A4	S1	60 150	-
131 000	139 400	8 400	D1	S2	45 750	-
139 400	144 000	4 600	A1 - A2	S1	64 750	-
144 000	148 000	4 000	B1	S2	49 750	-
148 000	150 000	2 000	A1 - A2	S1	66 750	-
150 000	151 500	1 500	B1	S1	68 250	-
151 500	152 000	500	A1 - A2	S1	68 750	-
152 000	156 000	4 000	B1	S2	53 750	-
156 000	158 000	2 000	C2	S3	31 600	-
158 000	164 000	6 000	A3 - A4	S1	74 750	-
164 000	165 200	1 200	C2	S3	32 800	-
165 200	167 000	1 800	D1	S2	55 550	-
167 000	168 700	1 700	A1 - A2	S1	76 450	-
168 700	171 700	3 000	D1	S1	79 450	-
171 700	175 400	3 700	A1-A2-A3	S1	83 150	-
175 400	178 200	2 800	D1	S1	85 950	-
178 200	181 000	2 800	A1-A2-A3	S1	88 750	-
181 000	185 000	4 000	C2	S2	59 550	-

Table E-15

Quantity Estimation for Trackwork

Item	Location										
	Montreal 0+000 to 24+000			Laval 24+000 to 62+000			Mirabel 27+000 to 62+000			Quebec 62+000/ 80+000	Ontario 80+000 to 185+000
	Rail	Commuter	C.N.	Rail	Commuter	C.N.	Rail	Commuter	C.N.	Rail	Rail
Rock Excavation (m^3)	40 000	40 000	300	-	-	-	-	-	-	-	-
Rock Tunneling (m^3)	-	-	-	-	-	-	850 000	-	-	-	-
Top-Soil Removal (m^3)	50 000	50 000	20 000	11 000	11 000	6 000	190 000	7 000	4 000	110 000	700 000
Soil Excavation (2nd class)(m^3)	280 000	280 000	33 000	30 000	30 000	15 000	830 000	14 000	7 000	650 000	3 000 000
Borrowed Material (m^3)	200 000	200 000	100 000	140 000	140 000	100 000	400 000	50 000	50 000	840 000	2 600 000
Ballast (m^3)	100 000	80 000	33 000	13 000	13 000	7 000	140 000	180 000	9 000	73 000	430 000
Sub-Ballast (m^3)	48 000	36 000	15 000	6 000	6 000	3 000	80 000	8 000	4 000	42 000	2 500 000
Road Foundation (m^3)	69 000	69 000	30 000	5 000	5 000	3 000	210 000	8 000	4 000	120 000	700 000
Asphalt for Roadwork (m^3)	8 000	8 000	3 000	5 000	5 000	3 000	15 000	2 000	2 000	18 000	100 000
Road Foundation (m^3)	28 000	28 000	12 000	17 000	17 000	12 000	56 000	6 000	6 000	68 000	360 000

Table E-16

Location, Type and Arrangement of Turnouts

Location: Kilometric Point	Turnouts and Other Track Equipement by Type					
	Remote-controlled Turnouts				Manual Turnouts (Low Speed)	Protected Diamonds Crossings (between 2 tracks)
	High Speed		Low Speed			
	Crossover Arrangement	Simple Turnout	Crossover Arrangement	Simple Turnout		
0 000	–	–	–	6	–	3
5 400	4	2	–	–	–	1
8 000	–	–	–	–	4	–
11 600	–	–	4	2	5	3
13 400	–	–	–	–	3	–
16 200	4	–	–	–	3	–
20 000	–	–	–	–	1	–
28 800	–	–	2	–	–	–
31 000	4	–	2	–	–	–
37 000	–	–	–	–	–	2
44 000	–	4	–	–	–	1
46 000	2	–	–	–	–	–
73 000	4	–	–	–	–	–
95 500	4	–	–	2	–	2
102 250	–	–	–	–	–	3
118 000	4	–	–	–	–	–
123 000	–	–	–	–	2	–
139 000	4	–	–	2	–	–
151 250	–	–	4	–	–	2
162 000	4	–	–	–	–	–
184 150	–	–	4	1	–	2
Total Number of Turnouts	34	6	16	13	18	19

Notes:
1. Turnouts by four in a crossover arrangement are laid out as two successive single crossovers, not as a double crossover.
2. Low-speed remote-controlled turnouts are used:
   - between HSR tracks near stations;
   - between one HSR track and another track (freight or commuter);
   - for HSR emergency sidings.
3. Manual turnouts are used exclusively for freight tracks.

E.4 Grade Separation Structures

This section concerns grade separation structures, thereby providing complementary information to Sub-section 5.6.1.

E.4.1 Need for and Types of Grade Separation Structures

Table E-17 provides detailed information on the treatment of every cross road along the route from Montreal to Ottawa, thereby complementing Table 5-3.

For every road-rail crossing, Table E-17 gives the number of tracks along the Rail route (HSR tracks, as well as commuter tracks, and freight tracks if applicable), the number of traffic lanes on the cross road (or the number of tracks in case of a rail-Rail crossing), and the type of structure used for grade separation (or whether the cross road is closed if such is the solution envisionned). As a result, Table E-17 formulates the requirements for grade separation structures for the whole route.

Three basic types of typical structures are considered in this study: the rail bridge that allows a street-under-Rail grade separation in urban and suburban areas, the overpass that allows a highway-over-Rail grade separation in rural areas, and the narrower road-over-Rail structure for rural roads other structures, considered as "special", are discussed in Sub-sections E.4.5, E.4.6 and E.4.7.

Most often, the structures mentioned in Table E-17 will be built where there is presently only a level crossing (or even no track at all). In several cases, as indicated in the table, an existing structure will have to be rebuilt because it is too old, or, more frequently, because it is too narrow and or not properly located to accomodate the new HSR tracks and their location on one side of the right-of-way.

The three typical structures will now be summarily described.

Table E-17

Location of Grade Separation Structures

(Page 1 of 4)

Map	Kilometric Point		Cross Road Identification	Number of Tracks	Number of Road Lanes	Type of New Structure or Work Required
2	6	300	Graham & Laird Blvd.	4	4	None (Existing)
2	6	650	Jasper-Lazard Street	4	2	Permanent Closure
2	7	350	Boul. Métropolitain	4	6	None
2	8	450	Eastern Junction (CN)	4	1	Rail over Rail (S)
2	8	700	Chemin Côte-Vertu	5	4	Street Under Rail(R,F)
2	9	950	Boul. Henri-Bourassa	5	6	None (Existing)
2	10	950	O'Brien Blvd.	5	4	Street under Rail (P)
2	11	600	Grenet Street	5	4	Street under Rail(R,P)
2	11	800	Boul. Laurentien	5	4	Street under Rail(R,P)
2	13	500	Boul. Toupin	5	4	Street under Rail (P)
3	16	100	Autoroute 13	5	6	None (Existing)
3	17	600	Alexander Street	5	4	Street under Rail (F)
3	19	950	11e Avenue	5	4	Street under Rail (F)
3	20	850	Boul. Gouin Ouest	5	4	Street under Rail (F)
3	21	400	Chemin des Sources	5	4	Detour Pedes.Cross.(F)
3	24	000	Chemin du Tour	5	2	Street under Rail (F)
3	24	450	Rang du Bord de l'eau	5	4	Street under Rail(R,F)
3	24	600	Terrasse Fournier	5	2	Closure
3	25	100	Graveline Road	5	2	Closed. New Access
3	25	950	Les Cèdres Street	5	2	Street under Rail (F)
3	26	700	Boul. Les Erables	5	4	Street under Rail (F)
3	27	400	Boulevard du Lac	5	4	Street under Rail (F)
3	28	050	Chemin d'Oka	5	4	Street under Rail(R,F)
3	28	600	Henri-Dunant Street	5	4	Street under Rail (F)
3	30	050	Autoroute 640	5	6	None (Existing)
3	34	500	Chemin Sud Pte Rivière	2	2	Highway over Rail (P)
3	34	800	Village Street	2	2	Closure
3	35	100	Montée Laurin	2	2	Highway over Rail (P)
4	37	400	Quebec Highway 148	3	2	Highway over Rail (P)
4	38	450	Côte-des-Corbeils	3	2	Closure, new Access
4	41	300	Rural Road	2	2	Road over Rail (P)
4	44	200	CN Track	2	1	Rail over Rail (F)
4	44	750	Côte-des-Anges	2	2	Road over Rail (F)
5	45	250	CP Track	2	1	Rail over Rail (F)
5	46	100	Rural Road	2	2	Closure
5	48	300	Mirabel Airport	2	-	Tunnel 1,7 km long.(S)

Table E-17

Location of Grade Separation Structures

(Page 2 of 4)

Map	Kilometric Point	Cross Road Identification	Number of Tracks	Number of Road Lanes	Type of New Structure or Work Required
4	52 350	Rural Road	2	-	Closure
4	54 650	Quebec Highway 148	2	2	Highway over Rail (P)
4	55 250	Rural Road	2	2	Closure. New Access
4	59 650	Rural Road	2	2	Closure
4	64 200	Rural Road	3	2	Road over Rail (P)
4	68 900	Rural Road	3	2	Detour
4	69 300	Rural Road (Kilowen)	3	2	Road over Rail (P)
4	69 700	Rural Road	3	-	Detour
6	70 300	Rural Road	2	2	Road over Rail (P)
6	71 450	Rural Road	2	2	Closure
6	74 350	Rural Road	2	2	Closure
6	76 300	Rural Road	2	2	Road over Rail (F)
6	77 350	Quebec Highway 337	2	2	Highway over Rail (F)
6	80 000	Quebec Highway 334	2	2	With Ottawa River (S)
6	81 000	Rural Road	2	2	With Ottawa River (S)
6	82 250	Rural Road	2	2	Road over Rail (F)
6	83 700	Highway 417	2	4D	Expressway over Rail(F)
6	85 900	Rural Graveled Road	2	2	Closure
6	88 650	Rural Road	2	2	Road over Rail (F)
6	90 200	Rural Graveled Road	2	2	Closure
7	94 200	Rural Graveled Road	2	2	Road over Rail (P)
7	96 350	Highway 417	3	4D	Expressway over Rail(RF
7	96 600	Graveled road	3	2	Road over Rail (F)
7	103 200	Ontario Highway 34	3	2	Highway over Rail (F)
7	104 500	Rural Road	3	2	Road over Rail (F)
7	106 200	Private Road	3	-	Farm Crossing
7	107 500	Rural Road	3	2	Road over Rail (F)
8	109 950	Rural Graveled Road	3	2	Closure
8	111 850	Rural Road	3	2	Road over Rail (F)
8	115 550	Rural Graveled Road	3	2	Road over Rail (F)
8	116 650	Rural Graveled Road	3	2	Closure, Detour
8	119 650	Rural Graveled Road	3	2	Closure, Detour
8	119 900	Rural Graveled Road	3	2	Closure
8	122 950	Rural Road	3	2	Road over Rail (F)
8	123 350	Rural Graveled Road	3	2	Closure, Detour

Table E-17

Location of Grade Separation Structures

(Page 3 of 4)

Map	Kilometric Point		Cross Road Identification	Number of Tracks	Number of Road Lanes	Type of New Structure or Work Required
9	126	000	Rural Graveled Road	2	2	Closure
9	127	550	Rural Graveled Road	2	2	Closure
9	129	400	Rural Graveled Road	2	2	Closure
9	129	900	Rural Road	2	2	Road over Rail (F)
9	131	850	Rural Graveled Road	2	2	Closure
9	132	450	Rural Graveled Road	2	2	Closure
9	134	800	Rural Graveled Road	2	2	Closure
9	135	500	Rural Graveled Road	2	2	Closure
9	138	600	Rural Graveled Road	3	2	Road over Rail (F)
9	141	350	Rural Road	3	2	Road aver Rail (P)
9	143	550	Private Road	3	2	Farm Crossing
9	144	850	Rural Graveled Road	3	2	Closure. New Access
9	146	200	Rural Road	3	2	Road over Rail (F)
9	147	550	Rural Graveled Road	3	2	Closure
10	148	900	Rural Graveled Road	3	2	Road over Rail (P)
10	149	800	Rural Graveled Road	3	2	Closure
10	150	550	Rural Graveled Road	3	2	Closure
10	151	250	Rural Graveled Road	3	2	Closure
10	152	150	Rural Graveled Road	3	2	Road over Rail (F)
10	153	550	Rural Graveled Road	3	2	Closure
10	155	750	Rural Graveled Road	3	2	Road over Rail (F)
10	157	000	Rural Graveled Road	3	2	Road over Rail (F)
10	158	350	Rural Graveled Road	3	2	Closure
10	159	850	Rural Graveled Road	3	2	Closure
10	161	200	Rural Graveled Road	3	2	Road over Rail (P)
10	162	450	Rural Graveled Road	3	2	Closure
10	164	000	Rural Graveled Road	3	2	Road over Rail (P)
10	165	400	Rural Graveled Road	3	2	Closure
10	166	850	Rural Graveled Road	3	2	Road over Rail (F)
10	168	200	Rural Graveled Road	3	2	Closure, Detour
10	168	450	Rural Graveled Road	3	2	Road over Rail (P)

Table E-17

Location of Grade Separation Structures

(Page 4 of 4)

Map	Kilometric Point		Cross Road Identification	Number of Tracks	Number of Road Lanes	Type of New Structure or Work Required
11	170	000	Rural Graveled Road	3	2	Road over Rail (P)
11	175	900	Rural Graveled Road	3	2	Closure, Detour
11	176	050	Rural Graveled Road	3	2	Road over Rail (P)
11	178	150	Anderson Road	3	4D	Highway over Rail (P)
11	180	950	Highway 417	3	6D	Expressway ov.Rail (PR
11	182	100	Inness Road	3	4D-2	Highway over Rail (F)
11	183	050	Michael Road	3	2	Highway over Rail (F)
11	183	300	Triole Road	3	2	None (already closed)
11	183	450	St-Laurent Blvd.	3	4D	Highway over Rail (RF)
11	184	500	Belfast Road	3	2	Road over Rail (F)

Symbols:

P: Refers to a structure built on Piles.

F: Refers to a structure built on Footings.

R: Refers to a structure built to replace an existing structure.

S: Refers to a special structure that is estimated individually, not with a unit cost per deek area.

4D: Refers to a four lane divided expressway where the distance between the pairs of lanes is enough for each pair to be considered as a two-lane highway.

6D: Refers in similar fashion to a six-lane divided expressway.

E.4.2 Street-under-Rail Structures

The typical street-under-Rail grade separation is a rigid-frame reinforced-concrete structure with a deck thickness of 1 000 mm. As this structure is built where there is a need to carry five tracks, its deck will be 29 000 mm wide.

The deck will rest on and be rigidly connected to three vertical walls, two outside walls working as abutments and the central one as an intermediate support leaving two clear spans of 12 000 mm over the street: that is enough for two traffic lanes of 4 000 mm each and a raised sidewalk. Each outside wall will also anchor two reinforced-concrete retaining walls running the full length of the underpass.

The construction method must be such that rail traffic will be maintained on one track and road traffic on two lanes at all times. Except in four cases (Graham Blvd., Boul. Métropolitain, Henri-Bourassa, Autoroute 13), all existing structures of this type must be replaced by new ones. When doing so, a temporary rail bridge will first be built and rail traffic switched to it; then the old structure will be demolished and replaced by the first half of the new structure. The rail traffic will then be switched to the new structure, the temporary rail bridge demolished, and the new structure completed. Even in this case, bi-directional automobile traffic will be maintained during construction.

Details on street-under-Rail underpasses envisioned in this study are given in Table E-18. On the basis of preliminary site inspections, it is presumed that the geometry of surrounding streets and the nature of neighboring buildings and structures would permit construction of the new structure. Should detailed surveys or investigations eventually demonstrate that such is not the case, consideration would have to be given to closing the cross road.

Table E-18

Characteristics of Street-under-Rail Structures

Name of Cross Road	Location		Number of		New or Rebuilt (N or R)	Foundation
	City	Km Points	Tracks	Lanes		
Côte-Vertu	Saint-Laurent	8+700	5	4	R	Piles
O'Brien Blvd.	Montreal	10+950	5	4	N	Piles
Grenet St.	Montreal	11+600	5	4	R	Piles
Boul. Laurentien	Saint-Laurent	11+800	5	4	R	Piles
Boul. Toupin	Saint-Laurent	13+500	5	4	N	Footings
Alexandre St.	Pierrefonds	17+600	5	4	N	Footings
Onzième Avenue	Roxboro	19+950	5	4	N	Footings
Boul. Gouin Ouest	Roxboro	20+850	5	4	N	Footings
Chemin du Tour	Laval	24+000	5	2	N	Footings
Du Bord de L'eau	Laval	24+450	5	4	R	Footings
Les Cèdres St.	Laval	25+950	5	2	N	Footings
Boul. Les Erables	Laval	26+700	5	4	N	Footings
Boul. du Lac	Deux-Montagnes	27+400	5	4	N	Footings
Chemin d'Oka	Deux-Montagnes	28+050	5	4	R	Footings
Henri-Dunant	Deux-Montagnes	28+600	5	2	N	Footings

Note: The information shown above is summarized in the first block of rows in Table 5-4.

The cost of this type of structure will also vary with the type of foundation required depending on the nature of the sub-soil. Unit costs are given in Table 5-5.

E.4.3 Highway-over-Rail Structures

The typical road-over-Rail grade separation is a box-type rigid-frame structure made of reinforced concrete, consisting of a deck resting on and rigidly connected to vertical walls working as abutments. Its dimensions will vary with the number of tracks being overpassed and depending on whether the roadway is a numbered highway or a simple rural road. The cost will further vary with the nature of the sub-soil. The design principles, materials, and construction methods will be the same in all cases.

For a numbered highway over two tracks, the deck width will be 12 900 mm outside guardrails, the deck thickness 650 mm, and the clearance between abutment faces will be 12 000 mm (Figure E-9). Each vertical wall will anchor wing-type retaining walls that will extend 11 000 mm on each side of the structure, almost parallel to the tracks; there walls will be dimensioned and designed to retain the fill supporting the roadway and let it maintain a 2.1 natural slope.

In the case of three tracks, the deck will have the same width, but the slab will be 900 mm stick due to the greater span. The clearance between abutment faces will be 17 100 mm (Figure E-10).

In the case of an expressway, given the distance between the two pairs of lanes, two separate highway-over-Rail structures will be built one after the other, while the road traffic is being detoured under the other.

The requirements for highway-over-Rail structures are summarized in Table E-19.

Table E-19

Characteristics of Highway-over-Rail Structures

Name of Cross Road	Location		Number of		New or Rebuilt (N or R)	Foundation Type
	City	Km Points	Tracks	Lanes		
Chemin sud de la Petite Rivière	St-Eustache	34+500	2	2	N	Piles
Montée Laurin	St-Eustache	35+100	2	2	N	Piles
Que. Highway 148	Mirabel	37+400	3	2	N	Piles
Côte-des-Corbeil	Mirabel	41+300	3	2	N	Piles
Côte-des-Anges	Mirabel	44+750	2	2	N	Footings
Que. Highway 148	Mirabel	54+650	2	2	N	Piles
Rural Road	St-Placide	64+200	3	2	N	Piles
Rural Road	Kilowen	69+300	3	2	N	Piles
Rural Road	Kilowen	70+300	2	2	N	Piles
Rural Road	St-André Est	76+300	2	2	N	Footings
Que. Highway 337	St-André Est	77+350	2	2	N	Footings
Rural Road	Pointe-Fortune	82+250	2	2	N	Footings
Ontario High. 417	Prescott Co.	83+650	2	2	N	Footings
Ontario High. 417	Prescott Co.	83+750	2	2	N	Footings
Rural Road	St-David's	88+650	2	2	N	Footings
Ontario High. 417	St-David's	96+300	4	2	R	Footings
Ontario High. 417	St-David's	96+400	4	2	R	Footings
Ontario High. 434	VanKleek Hill	103+200	3	2	N	Footings
Rural Road	Vankleek Hill	104+500	3	2	N	Footings
Rural Road	Vankleek Hill	107+500	3	2	N	Footings
Rural Road	Caledonia Front	111+850	3	2	N	Footings
Rural Road	Alfred	122+950	3	2	N	Piles
Rural Road	Plantagenet	129+900	2	2	N	Piles
Rural Road	Plantagenet	141+350	3	2	N	Piles
Rural Road	Bourget	146+200	3	2	N	Footings
Anderson Road	Ottawa Blackburn	178+150	3	2	N	Piles
Ontario High. 417	Ottawa	180+900	4	2	R	Piles
Ontario High. 417	Ottawa	181+000	4	2	R	Piles
Iness Road	Ottawa	182+100	3	4	N	Footings
Michael Road	Ottawa	183+050	3	2	N	Footings
Boul. St-Laurent	Ottawa	183+250	3	2	R	Footings
Boul. St-Laurent	Ottawa	183+650	3	2	R	Footings
Belfast Road	Ottawa	184+500	3	4	R	Footings

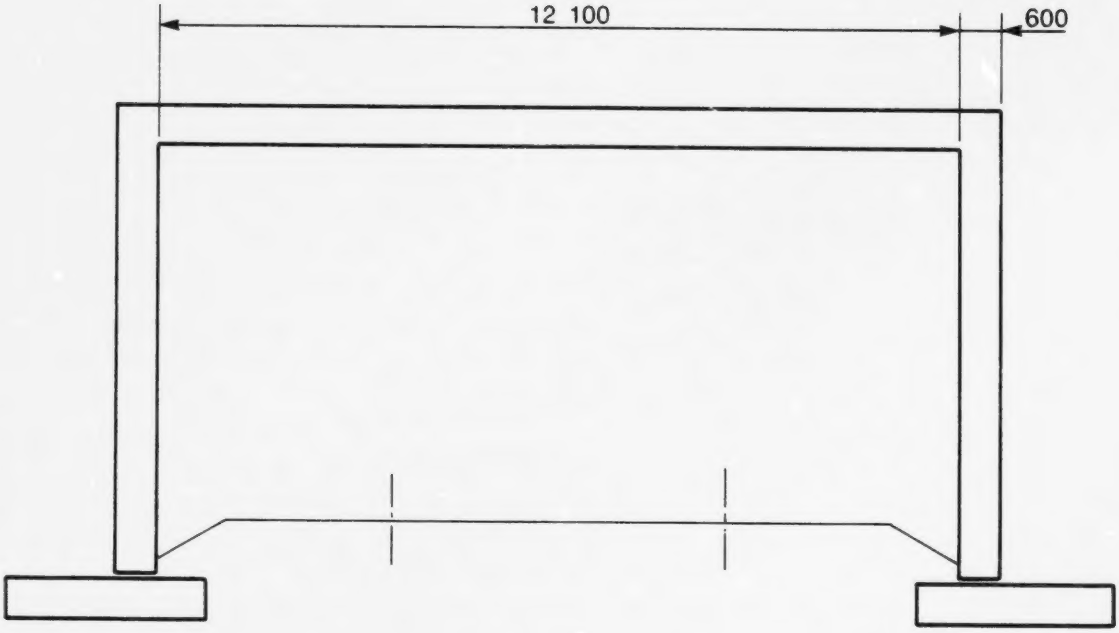


Figure E-9 Typical Highway-over-Rail Structure for Two Tracks

E.4.4 Road-over-Rail Structures

In the case of road-over-Rail structures, the chief difference seems to be in the width of the deck, but the problem is more complex.

Indeed, design standards for grade separation structures are conceived in relation to their normal domain of application: in rural areas, grade separation structures are normally built only on numbered highways, while low-volume country roads are either detoured or simply equipped with level crossing protection equipment. Consequently the minimum deck width allowed by governmental standards is approximately 12 000 mm.

In this study, however, the increase in risk that justifies the grade separation does not stem from an increase in the volume of automobile traffic as is usually the case, but rather from an increase in the speed and frequency of rail traffic. Rural roads for which a structure is recommended in Table E-16 have a function such that they could not easily be detoured without penalizing villages, but are not likely to ever carry the automobile traffic that would normally justify a grade separation.

Consequently, a narrower structure should be adequate for the need in the foreseeable future. Such a structure however, is not acceptable under present regulations. It will be presumed that, given the relatively large number of such structures that would be needed, the regulation could change in time.

A structure with a 8 000 mm wide deck, that could be built at around 70% of the cost of a highway-over-Rail structure, is thus envisioned for the road-over-Rail grade separation. Requirements for such structures are summarized in Table E-20.

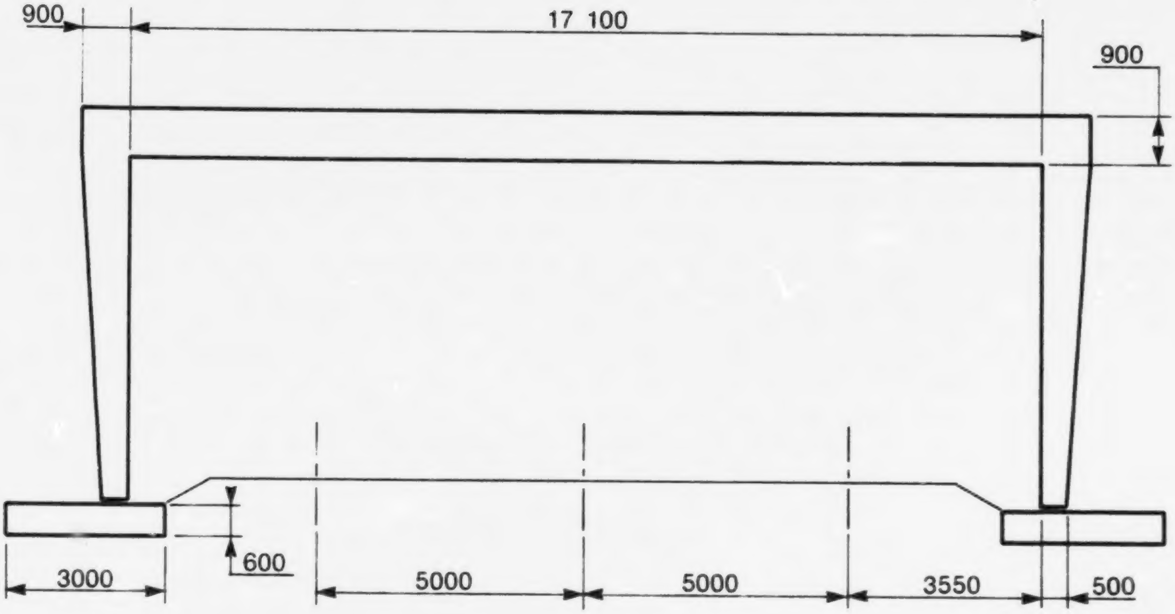

900
17 100
900
600
3000
5000
5000
3550
500

Figure E-10 Typical Highway-over-Rail Structure for Three Tracks

Table E-20

Characteristics of Road-over-Rail Structures

Name of Cross Road	Location		Number of		New or Rebuilt (N or R)	Foundation Type
	City	Km Points	Tracks	Lanes		
Gravel Road	-	94+200	2	2	N	Piles
Gravel Road	Stardale	96+600	3	2	N	Footings
Gravel Road	Caledonia Spring	115+550	3	2	N	Piles
Gravel Road	Pendleton	138+600	3	2	N	Footings
Gravel Road	-	148+900	3	2	N	Piles
Gravel Road	Hammond	152+150	3	2	N	Footings
Gravel Road	RMOC *	155+750	3	2	N	Footings
Gravel Road	RMOC *	157+000	3	2	N	Footings
Gravel Road	Leonard	161+200	3	2	N	Piles
Gravel Road	Ottawa-Carleton	164+000	3	2	N	Piles
Gravel Road	Navan	166+850	3	2	N	Footings
Gravel Road	Navan	168+450	3	2	N	Piles
Gravel Road	Ottawa-Carleton	170+000	3	2	N	Piles
Gravel Road	Blackburn	176+050	3	2	N	Piles

* RMOC: Regional Municipality of Ottawa-Carleton.

E.4.5 Special Structures

Along the Rail route, in the Town of Mount Royal, there is presently a station on the CN commuter service. That station is surrounded by two overpasses that are part of the traffic circle that marks the centre of the town. That station will be maintained when the existing commuter is improved in the future; when two new tracks are built, the existing structures must be replaced by new ones providing sufficient clearance for four tracks and for a central platform or two lateral platforms for the commuter service. COTREM has studied this problem in detail as part of their planning work. According to their studies, the cost of building two new structures would amount to $1,3 M. The route is in a cut in this area and residential streets run along that cut on both sides; when two additional tracks are built, the construction of retaining walls will become necessary. Their cost of construction from km 5+600 to km 6+700 will amount to $1,0 M.

E.4.6 Rail-over-Rail Structures

On the Rail route, there are crossings with other tracks at the following kilometric points:

- 5+400 (with a future COTREM commuter track);
- 8+400 (CN St. Laurent Subdivision);
- 11+600 (CN access to CN Cartierville Spur);
- 37+000 (CN Montfort Subdivision);
- 44+000 (CN Montfort Subdivision);
- 45+200 (CP Lachute Subdivision);
- 95+500 (CP M.&O. Subdivision);
- 102+250 (CN Hawkesbury Spur);
- 151+250 (CP M.&O. Subdivision);
- 184+150 (CN Industrial Spur).

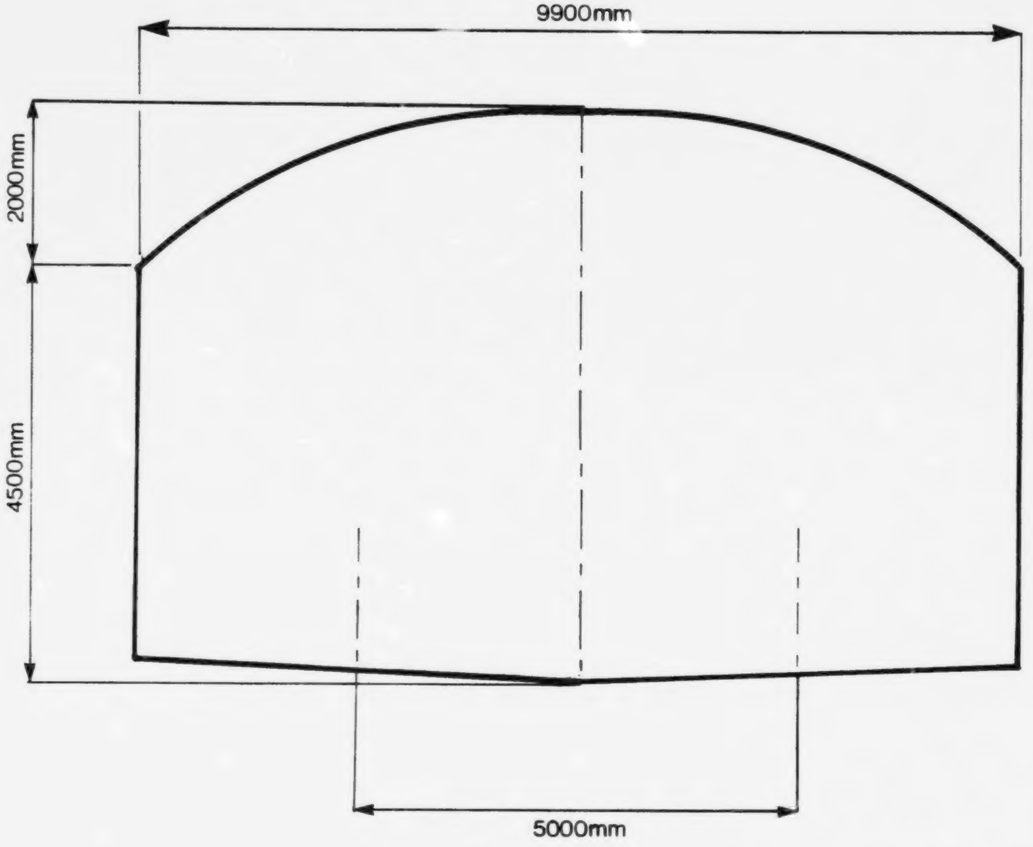

9900mm
2000mm
4500mm
5000mm

Figure E-11 Clearances for the Tunnel at Mirabel

In most cases, there is so little traffic on the other track that an adequately-protected level crossing will allow the HSR trains to proceed in complete safety (as the crossings will be duly protected) without being delayed (as HSR will have priority) and without unduly delaying the other rail traffic (as short HSR trains traveling at 200 km/h will occupy these crossings for very brief periods).

A grade separation structure will be required only at km 8+400, as long freight trains, traveling at low speed near Taschereau yard on CN Saint-Laurent Subdivision, would otherwise cross two HSR tracks and two commuter tracks, implying possibly significant interference.

At that point, the Saint-Laurent Subdivision carries short distance freight traffic to the industrial areas in the eastern part of Montreal, and long distance freight traffic to the regions of Mauricie, Saguenay, Abitibi, and from there on to Chibougamau near James Bay.

Due to the increase in frequency along the CN Montfort Subdivision (HSR and commuter services), this crossing will have to be grade-separated. This work also has been studied and estimated by COTREM. The structure carrying the Saint-Laurent Subdivision over the Rail route would cost $1,1 M. In addition, the profile of the Saint-Laurent Subdivision will have to be changed, as for as and including a small yard in the town of Saint-Laurent: earthwork and track reconstruction are estimated to cost $0,4 M.

E.4.7 Tunnel at Mirabel

On the basis of available information, solid bedrock is found at 3 to 6 m below the surface in that area. One is naturally led to consider a bored tunnel which could be built without shoring, underpinning, or concrete lining, thus at a (relatively) low cost.

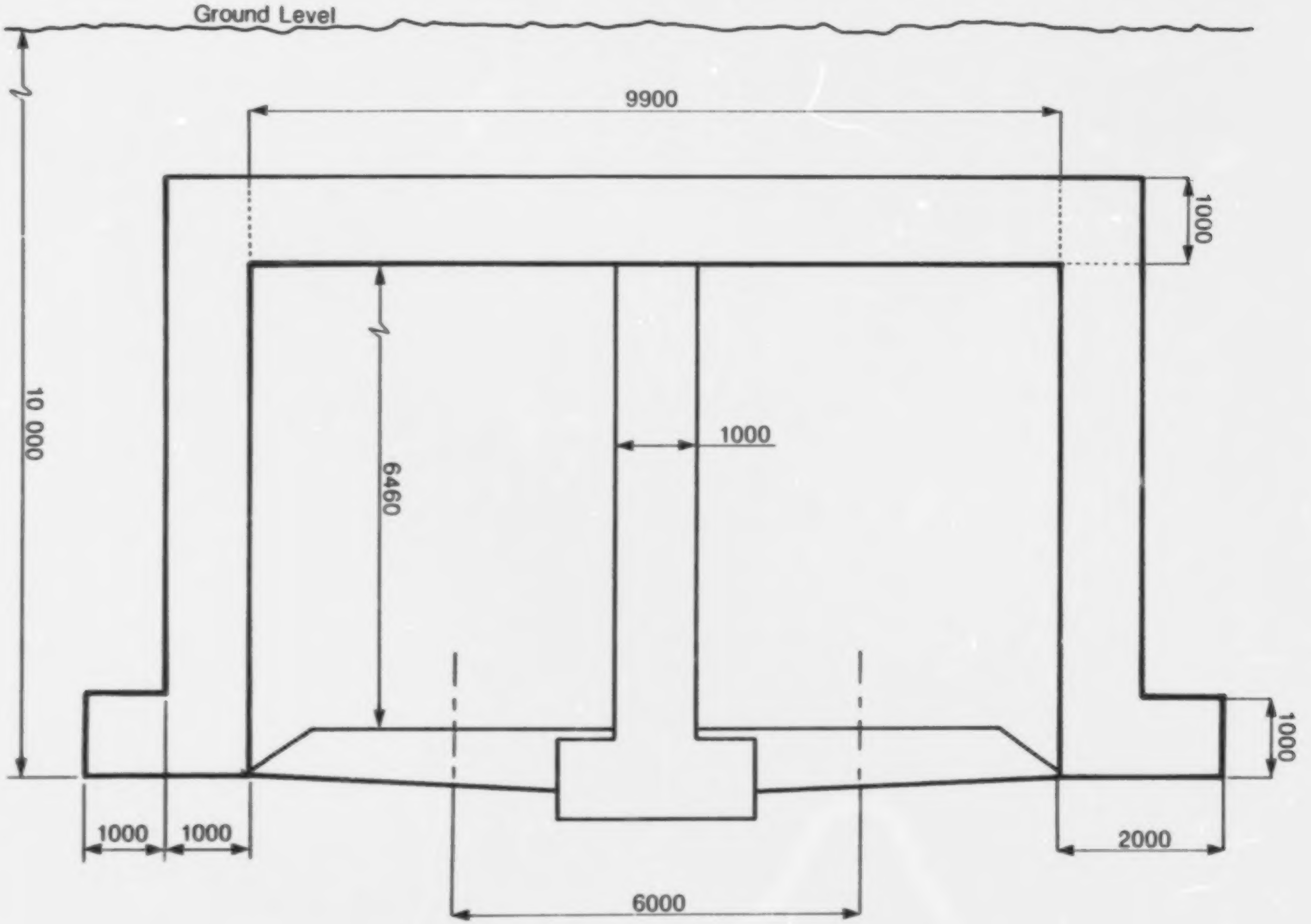

Ground Level
9900
10 000
1000
1000
6460
1000
1000
1000
1000
2000
6000

Figure E-12 Structural Dimensions for the Tunnel at Mirabel

Based on the clearances shown in Figure E-11, the tunnel would be approximately 6,5 high at the crown and 9,9 m wide, for an area of 58,3 m^3. The cost of boring such a tunnel, the work consisting only of rock excavation at $50/$m^3$, would amount to $2 915/m. Unfortunately, to have the necessary resistance, such a tunnel would need a rock cover of 25 to 30 m; to obtain it by lowering the tunnel would unduly lengthen it.

The solution, then, is to use a rigid-frame structure as shown in Figure E-12, when a tunnel is effectively needed, and to leave the tracks in an open cut elsewhere.

Refering back to Figure 4-2, it appears that a length of 1 480 m of tunnel is required, followed by an open cut of approximately 800 m, excluding the construction of a grade separation at Côte Saint-Jean.

The excavation required for the structure shown in Figure E-12 has a height of 11,0 m all across and a width of 15,0 m, for a cross-section of 165 m^2. The cost of boring that excavation, at $50/$m^3$, amounts to $8 250/m. For a length of 1 480 m, that is a cost of $12,21 M. The excavation must be extended the equivalent of 200 m at each end to reach ground level, for an additional $3,30 M.

The structure itself requires the following quantities of materials, for every meter of length: 44 m^3 of structural concrete (at $160/$m^3$ in place) and 4 000 kg of reinforcing steel (at $0,75/kg in place), for a total linear cost of $10 040/m.

The basic structure is needed for 1 480 m and should cost $14,86 M. That structure must be extended the equivalent of 400 m to reach ground level for an additional $4,02 M; this includes the cost of the grade separation at Côte Saint-Jean, including the necessary road.

The direct capital cost of the tunnel and its approaches is estimated at $34,4 M. The costs of the track and the catenary in the tunnel are included elsewhere.

E.5 Bridges and Culverts

The width of river crossings to be bridged on the Rail route ranges from 10 m to 800 m; whenever the creek or stream is narrower than 10 m, only a culvert will be used.

For the purpose of this study, smaller rivers were classified as being either 10 m wide or 40 m wide. On that basis, there would be nine 10 m bridges and one 40 bridge.

The typical 10 m bridge is a simply-supported deck resting on reinforced-concrete abutments (Figure E-13). The composite deck would consist of standard shape steel beams working jointly with the concrete slab. Ballast would be laid between the tracks and the deck. Normally built for two tracks, such bridges would be built to carry three tracks in three instances.

The typical 40 m bridge is also a simply-supported deck resting on reinforced-concrete abutments. In this case, however, custom-built steel beams made with welded plates would be used in the composite deck (Figure E-14).

When crossing Rivière du Nord and South Nation River, there are advantages in eliminating piers to reduce cost and to prevent ice accumulation problems during Spring thaw. In this case, the bridge would consist of a 100 m span steel truss resting on reinforced-concrete abutments; its dimensions are shown schematically in Figure E-15. In both instances, the bridges will carry two tracks laid on ties fixed directly to the structure.

Major river crossings near Montreal will pose special problems, for two reasons: the new bridges, which must carry five tracks in all cases, will be built to replace much narrower existing structures; and rail traffic will have to be maintained during construction.

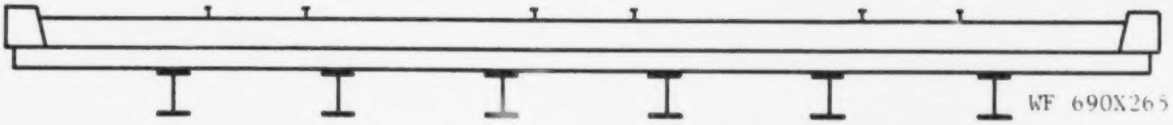


Figure E-13 Deck Cross-Section for a Three-Track 10-m Bridge

In each case, the river is divided into two branches at the crossing: a branch of 200 m in width and a narrower branch of 120 m; even the widths are the same (at the scale used) on both rivers.

The structural concept adopted is the following. To cross each wider branch, two steel trusses, each 100 m in span, will be used. To cross each narrower branch, a similar steel truss will be used with a 20 m composite span based on the same design as the 40 m span discussed previously.

The structural concept must respect the following constraints: the steel truss can not be built economically for more than 3 tracks; electrified commuter rail traffic must be maintained.

These constraints suggest the following construction approach: to build parallel bridges in succession, using a sequence such as the following. First, a complete series of 2-track bridges are built (two trusses for one branch and a truss and a deck for the other; the same for each river); these bridges are equipped complete with track and catenary. Second, rail traffic is switched to the new bridges and the old bridges are demolished. Third, a second, similar, series of bridges is built, each designed to carry three tracks.

With such a sequence, it is possible to provide crossings for 5 tracks within the existing right-of-way which, in the Laval islands in particular, can not be moved due to the proximity of houses.

The following unit costs will be used to estimate the construction cost of these bridges: $1,85 M for a 100-m 2-track truss, $0,6 M for a 2-track, 40-m span; these values were used previously. In addition, a 3-track bridge can be estimated to cost 40% more than a 2-track bridge of similar design and a 20-m span, 40% of the cost of a similar 40-m span. Demolition of a bridge would cost $0,5 M.

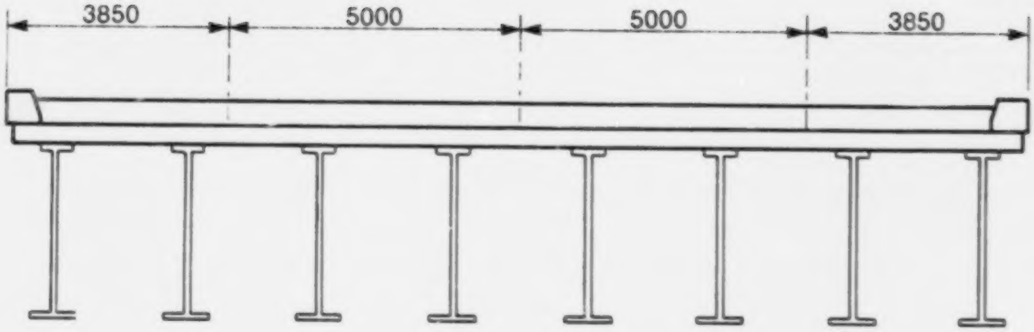

3850
5000
5000
3850

Figure E-14 Deck Cross-Section for a Three-Track 40-m Bridge

Thus, for each river, Phase I would cost \$3,7 M for the wider branch (2 x \$1,85 M) and \$2,1 M (\$1,85 M + 40% x \$0,60 M) for the narrower one. Phase II would cost \$1 M (\$0,5 M for each branch). Phase III would cost \$5,2 M (\$1,40 x 2 x \$1,85 M) for the wider branch and \$2,9 M (\$1,40 x \$1,85 M + 1,40 x 40% x \$0,60 M) for the narrower branch.

The direct capital cost of each complete crossing would then be \$14,9 M.

In the case of the Ottawa River, the bridge will carry two tracks only and will not replace an existing structure; the river is 800 m wide at the crossing. The principle of simply-supported composite spans will be used here again, as Ottawa River is not navigable except by pleasure craft at the crossing. The bridge will be approximately 20 m above the river. As a result, the structure will be extended to a total length of 1 120 m to carry the tracks above riverside highways in Ontario and Quebec.

Requirements for bridges are summarized in Table E-21, while requirements for culvert work are given in Table E-22.

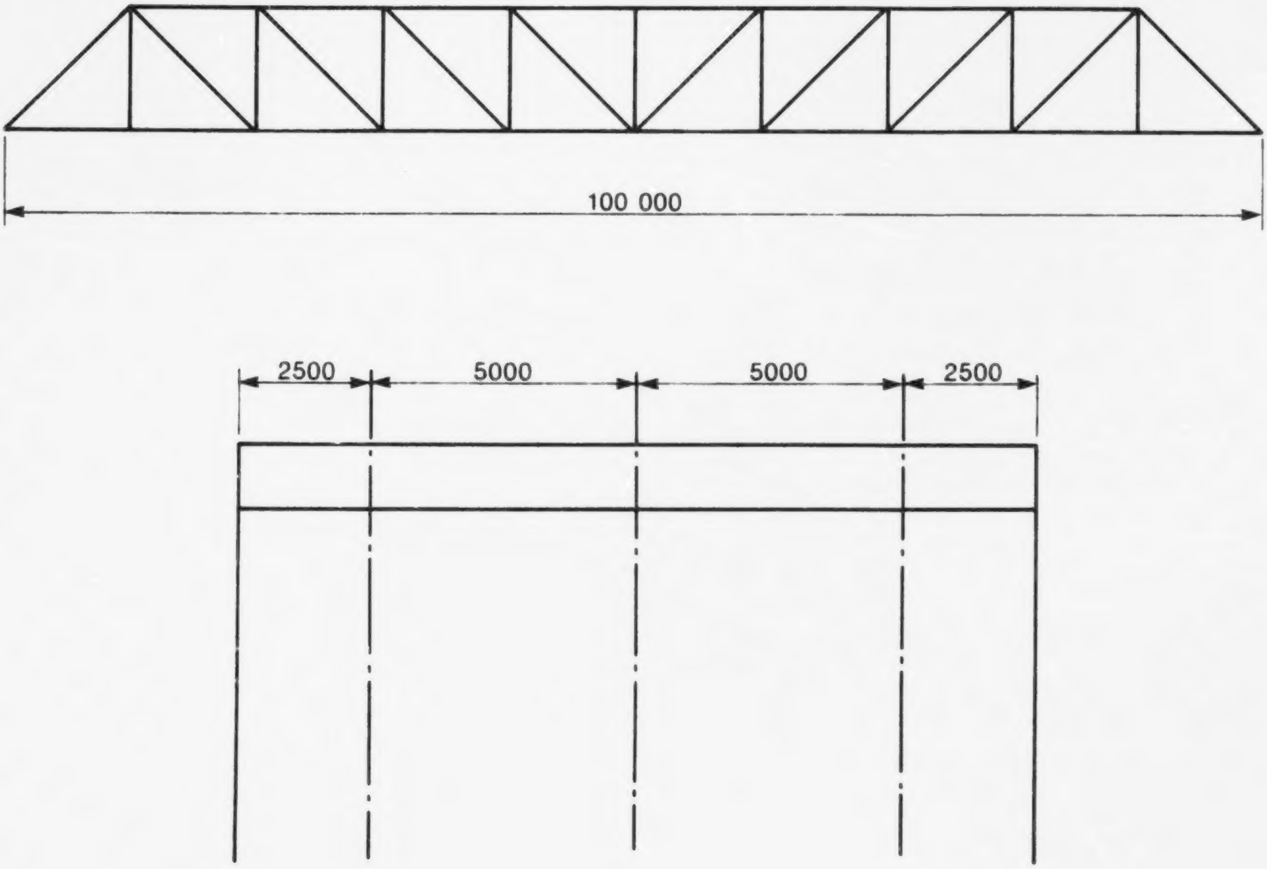

100 000
2500
5000
5000
2500

Figure E-15 Concept of a Steel Truss for a 100-m Rail Bridge

Table E-21

Bridges on the Rail Route

Map	km	Crossing	Tracks	Length (m)	Piles or Footings	New or Rebuilt
3	23 350	Rivière des Prairies	5	200	P	R
3	24 250	Rivière des Prairies	5	120	F	R
3	26 800	Rivière des Mille-Iles	5	120	P	R
3	26 950	Rivière des Mille-Iles	5	200	P	R
3	34 600	Rivière du Chêne	2	10	P	N
4	36 400	Rivière du Chêne	2	10	P	N
4	37 050	Rivière du Chêne	2	10	P	N
4	55 100	Rivière du Chêne	2	10	P	N
6	71 200	Rivière St-André	2	100	P	N
6	78 000	Rivière du Nord	2	100	P	N
6	80 100	Rivière des Outaouais	2	725	P	N
8	112 100	Mill Creek	3	10	F	R
8	115 700	Des Atocas Creek	3	10	P	R
9	128 500	South Nation River	2	100	P	N
9	139 500	Dickinson Creek	3	10	P	R
9	141 750	Cobbs Lake Creek	3	40	P	R
10	165 900	Creek	3	10	P	R

Table E-22

Culverts on the Rail Route
(Page 1 of 2)

Map	km	Location Description	Width (m)	New or Rebuilt (N or R)
D-2	10 550	Creek	35	R
	13 550	Creek	35	R
			70	
D-3	16 950	Bertrand Creek	35	R
	30 600	Ferry Creek	20	R
	31 000	Creek	20	R
	33 050	Girard Prud'homme	25	R
	33 650	Laurence Robinson	25	R
	35 500	Larose Creek	25	N
			150	
D-4	37 500	Creek	25	R
	40 550	Ditch	20	N
	41 700	Ditch	30	N
	44 300	Ditch	20	N
	52 800	Ditch	25	N
	56 700	Ditch	25	N
	59 050	Ditch	20	N
	66 950	Ditch	25	R
	68 450	Ditch	30	R
			220	
D-5	None			
D-6	73 250	Ditch	25	-
	77 300	Creek	50	-
	82 450	A Charette Creek	30	-
			105	
D-7	100 050	Little Rideau Creek	25	R
	104 700	Creek	20	R
	106 300	Blayneys Creek	30	R
	106 900	Blayneys Creek	30	R
			105	
D-8	118 000	Des Atocas Creek	20	R
	122 650	Creek	20	R
			40	

Table E-22

Culverts on the Rail Route
(Page 2 of 2)

Map	km	Location Description	Width (m)	New or Rebuilt (N or R)
D-9	128 000	Creek	25	N
	133 200	Black Creek	25	N
	135 700	Spring Brook Creek	20	N
	145 850	Creek	20	R
	146 900	Creek	20	R
			110	
D-10	149 200	Creek	20	R
	150 900	North Indian Creek	20	R
	151 800	Creek	20	R
	152 900	Creek	20	R
	154 850	Creek	20	R
	159 500	Creek	20	R
	160 060	Creek	20	R
	161 450	Creek	20	R
	163 750	Creek	20	R
	164 600	Creek	25	R
	167 650	Creek	25	R
			230	
D-11	171 650	Creek	20	R
	175 450	Creek	20	R
	180 550	Creek	20	R
	181 400	Green Creek	20	R
			80	
		TOTAL	1 110	

E.6 Stations

E.6.1 Space Requirements

Space requirements for stations were developed based on the need to supply an adequate capacity to handle peak loads in 2011.

Space requirement criteria were developed from an analysis of typical medium size VIA stations, such as that of Kingston. These criteria are the following: 1,67 m^2 per peak-hour passenger for waiting area and associated passenger-related amenities; 1,25 m^2 per peak-hour passenger for operation-related functions such as ticket counters, baggage and parcel handling facilities, and offices; for a total, then, of 2,92 m^2 per peak-hour passenger.

Table E-23, based on traffic data and forecasts given in Chapter 1, shows the space requirements for the four stations and intermediate steps in their derivation, which is as follows:

- mean annual boarding (in thousand directional trips in Table E-23) is based in on the median between the maximum and minimum total traffic forecasts shown in Table 1-14; this median is halved as boarding corresponds to directional traffic;
- mean daily boarding (in directional trips per day) is mean annual boarding divided by 365 days/year;
- mean hourly boarding (in directional trips or departures per hour) is mean daily boarding divided by 17,5 hours/day;
- peak hourly boarding is thrice mean hourly boarding (both parameters in directional trips/hour);
- concourse design capacity (in peak-hour passengers is 50% of peak hourly boarding: it presumes that the concourse population is turned over twice during the peak hour;
- area requirement (m^2) is concourse design capacity multiplied by 2,92 m^2/passenger.

Table E-23

Estimated Passenger Handling Capacity at Rail Stations

Station	Year	Mean Annual Boarding (1 000 trips)	Mean Daily Boarding (trips)	Mean Hourly Boarding (passengers)	Peak Hourly Boarding (passengers)	Concourse Design Capacity (pass.)	Area Requirement (m²)
Montreal (1)	1991	402	1 100	63	190	95	
	1996	483	1 325	76	225	115	
	2001	581	1 590	90	270	135	
	2006	617	1 690	97	290	145	
	2011	621	1 700	97	290	145	423
West Island (2)	1991	239	655	37	110	55	
	1996	287	785	45	135	65	
	2001	346	950	55	165	80	
	2006	367	1 005	57	170	85	
	2011	368	1 010	58	175	90	263
Mirabel (3)	1991	183	500	29	85	45	
	1996	199	545	31	90	50	
	2001	217	595	34	100	50	
	2006	223	610	35	105	55	
	2011	223	610	35	105	55	161
Ottawa (4)	1991	532	1 460	83	250	125	
	1996	652	1 785	100	300	150	
	2001	799	2 190	125	375	190	
	2006	851	2 335	133	400	200	
	2011	857	2 350	134	400	200	584

Notes:
1. Based on Montreal - West Island traffic volumes in Table 1-14.
2. Based on the difference between Montreal - West Island and West Island - Mirabel traffic volumes in Table 1-14.
3. Based on Montreal - based airport-related traffic volumes in Table 1-11.
4. Based on Mirabel - Ottawa traffic volumes in Table 1-14.

E.6.2 Central Station

At Central Station, the HSR service will use the existing platform between Tracks 13 and 14, which will be rebuilt as outlined below. To improve passenger service, and to handle increased volumes efficiently, the existing stairs will be replaced by two pairs of escalators: one pair for arrival and one for departure, presumatly. Each pair of escalators will open on a new control counter on the concourse level. An elevator for use by handicapped passengers and for service requirements will be placed in the existing stairway opening.

Table E-24 shows details on the estimated costs for these modifications. These estimates take into account the structural modifications implied by the proposed renovetions and the difficult conditions under which this work will be done.

E.6.3 West Island Station

This suburban station is the only one on the proposed system to be entirely a new construction. The complete facility will consist of a 275 m^2 station building (based on the area requirement given in Table E-23), a parking area with space for 200 cars, access and curb space for bus loading and kiss-and-ride, and two platforms. This facility will require the acquisition of a land parcel estimated at 6 000 m^2. This acquisition will be difficult due to the proximity of two CN rights-of-way (Doney Spur and Montfort Subdivision), Autoroute 13, Boulevard Gouin, residential areas, and a forest conservation area.

The parking lot was dimensioned based on the observed use of access modes from the West Island to Dorval Airport for domestic flights, as these flights (predominantly to/from Toronto) appear similar in duration and character to Montreal - Ottawa trips by HSR.

On account of the short internal between trains arriving from and departing for Ottawa during peak periods, two lateral platforms will be built to avoid weaving in passenger walking movements on platforms, thus improving safety. These platforms, raised at car floor height to allow direct movements into and out of coaches, will be 150 m long and 4 m wide. There should be sufficient width to implement both platforms together with 2 HSR tracks and two commuter tracks within the existing right-of-way, with the building on the South.

The inside (South) platform, used by incoming passagers, will be connected directly to the station building. The outside platform, used by outgoing passengers, will be reached using a tunnel under the tracks. The stairways at both ends of this tunnel will be equipped with an incline wheel chair elevator.

Estimated costs for land acquisition and construction for West Island Station are given in Table E-24.

E.6.4 Mirabel Airport Station

When the Terminal 1 building for Mirabel Airport was designed and built , space was provided in the basement for a future transit station. This is where the Mirabel Station for the HSR service will be built. This is the only station along the Rail route where there will be passenger movements into and out of the same train: the station must be designed accordingly.

Given short peak-period headways between successive trains in opposite directions, as well as to avoid the risks associated with conflicting passenger movements, three platforms will be built: thus, passengers will move into a train from one side and out of it from the other. All platforms will be 150 m long; external lateral platforms will be 4 m wide, while the central platform will be 6 m wide.

Each platform will be linked to the concourse level above by a pair of escalators. Furthermore, the central platform will be equipped with an elevator for use by handicapped passengers and for service operations.

The estimated costs of building these facilities and making the necessary modifications to the terminal building concourse are shown in Table E-24.

E.6.5 Ottawa Terminal

Two tracks will be used exclusively for the HSR service at the Ottawa VIA station. As it is expected that this will be the most intensive service operated there, it will be presumed that these tracks will be the nearest to the existing building.

Whereas, strictly, two platforms only are needed, three will be built to increase operational flexibility and to provide for future expansion. Each platform, raised at coach floor level, will be 150 m long and 4 m wide. Whereas the inner platform will connect directly with the station concourse, the two outer platforms will be linked to it by a new tunnel connecting into the existing tunnel.

It is presumed that the existing parking area and curb space are sufficient.

Capital costs for the necessary modifications are shown in Table E-24.

E.6.6 Other Station Costs

The cost of building tracks through stations are included in the infrastructure costs.

Table E-24

Construction Costs for Rail Stations

Station	Work (Unit)	Unit Cost ($)	Cost ($)
Central Station	.Create openings in the concourse floor(ea)	20 000	40 000
	.Demolish existing stairs and close	Global	20 000
	.Construct new structural colomns at each of two new opening (ea.)	40 000	80 000
	.Install 4 escalators (ea.)	120 000	480 000
	.Install 1 elevator (ea.)	120 000	120 000
	.Install 2 control counters (ea.)	15 000	30 000
	.Finishing	Global	30 000
	.TOTAL	-	800 000
West Island	.Land acquisition: 6 000 m^2 (\$/100 m^2)	2 666	160 000
	.Construction of a 275 m^2 building (\$/m^2)	545	150 000
	.Platforms: two 150 m x 4 m lateral	10	120 000
	.Construction of a tunnel with elevator	Global	80 000
	.Parking Lot and Outside Finishing	Global	170 000
	.TOTAL	-	680 000
Mirabel Airport	.Double openings in the concourse floor(ea)	30 000	100 000
	.Install 5 escalators (ea.)	120 000	600 000
	.Install 1 elevator (ea.)	120 000	120 000
	.Platforms: two 4 m x 150 m lateral (\$/m^2)	10	120 000
	.Platform: one 6 m x 150 m central (\$/m^2)	10	90 000
	.Finishing including control counters	Global	100 000
	.TOTAL	-	1130 000
Ottawa	.Platforms: two 4 m x 150 m lateral (\$/m^2)	10	120 000
	.Platform: One 6 m x 150 m central (\$/m^2)	10	60 000
	.Tunnel with incline elevator	Global	50 000
	.Finishing	Global	10 000
	.TOTAL		340 000

The cost of computer terminals and associated hardware for reservations and ticket sales are estimated as part of the station operation costs.

The concourse level area required at Central Station and Ottawa Terminal will be leased from Canadian National and VIA Rail respectively. The annual rental costs were estimated on the basis of prevailing rates for Class A downtown buildings. These rates are currently \$183/m^2 in Montreal and \$215/m^2 in Ottawa. These rental costs do not include various other charges such as: maintenance, electricity, security, taxes, etc. These costs are included as part of station operating costs and building maintenance costs.

As to Mirabel Airport Station, it is presumed that the space and services are made available free of charge by Transport Canada.

E.7 Power Supply Equipment

E.7.1 Location of Feed Points

The location and capacity of the feed points required for the rail electrification were determined from voltage drop and loading considerations, based on the expected train loads and the catenary system used. The basic data used is given in Table E-25.

From the above considerations, the maximum section length that one feed point can supply would be between 45 and 50 km. Sample calculations are shown in Table E-26.

From a consideration of the track route and existing transmission facilities, the obvious location of feed points is as shown in Figure E-16.

The above feed points would result in a maximum section length of 48 km between Carillon and the Blackburn Siding feed points. This section length could be reduced, if detailed studies show a need, since the above-mentioned Ontario hydro 230 kV line crosses the track route on two more occasions on its way to St. Isidore and l'Original substations: at km 145+500 near Bourget and at km 109+500 near Caledonia Front.

The above arrangement with three feed points should be considered the absolute minimum requirements for the expected 1991 to 2011 Rail traffic and speed levels.

Table E-23

Basic Data for Power Supply Equipment Dimensioning

Train Speed (km/h)	Train Load (kVA)	Power Factor (pf)
Starting	7 000	0.3
30	4 500	-
60	5 000	-
110	7 000	-
200	3 300	0.85

Notes: 1. Assumed train efficiency: 85%.

2. Catenary: 25 kV AC, 60 Hz.

3. Catenary impedance - (0.08 + j0.3) Ω/km based on double track catenary.

Table E-26

Sample Calculation for Power Supply Dimensioning

Starting Conditions

Assume maximum of one train strat per section

Minimum locomotive starting voltage = 17 kV

= 68% rated voltage

Starting load = 7000 kVA at 0.3 power factor

= 480A at 17 kV/85% efficiency / angle of -72.5°

Catenary impendance = $(0.08 + j0.3)\ \Omega/\text{km}$

= $0.31\ \Omega$ at an angle of 75°

Normal supply voltage = 27.5 kV

= 110% rated voltage

Voltage drop available for starting = 110 - 68 = 42%

Assume 7% voltage drop for utility and trackside substation

Catenary voltage drop = 25%

$\therefore \frac{25}{100} \times 25000 - 480 \times 0.31 \times L$

where L = catenary length

L = 42 km

Running Conditions

Assume 2 trains / section at 200 km/h

Minimum locomotive running voltage = 90% rated voltage

Allowable catenary voltage drop = 110 - 90

= 20%

Train load = $2 \times \frac{3300}{.85}$ = 7765 kVA at 0.85 power factor

= 354A at 90% rated voltage and an angle of -32°

$\frac{20}{100} \times 25000 = 345 \times 0.31 \times L$

L = 47 km

E.7.2 Schematic Design

Duplicate transformers are provided to allow for loss of one transformer. Loss of supply to a complete station would, however, result in considerably reduced system performance.

No problems are foreseen for the supply utilities in accepting the single phase train loads. Even with two trains starting on a section at the same time, the total section load will be less than 15 MVA, which, for a 1% unabalance, would require a short circuit level of 1 500 MVA.

A schematic single line-diagram of the power supply and catenary systems is given in Figure E-17, which shows the feeder stations, phase break stations, and section stations.

Special arrangements may be required at the Montreal and Mirabel terminations, because of the tunnel sections. Fast, convenient isolation of the catenary within the tunnel is normally required from a safety standpoint. Figure E-18 shows sketches of typical arrangements. For the Mirabel termination, the phase break and tunnel isolation are combined in one station.

Additional switching arrangements will also be required for sidings and maintenance facilities. These cannot be detailed until the final track arrangement is known.

The switching arrangement shown at the feeder stations provides maximum reliability of supply for the catenary, but assumes that both supply transformers are connected to the same pair of phases on the utility network. If the utility requires each transformer to be connected on different phases, the switchgear arrangement would then be similar to the phase break stations with a slight loss of flexibility of operation.

It is assumed that modern telecommunication systems, such as fibre optic cable, will be used for the new line. However, to avoid interference with local systems, it is assumed that return conductor and booster transformers will be provided.

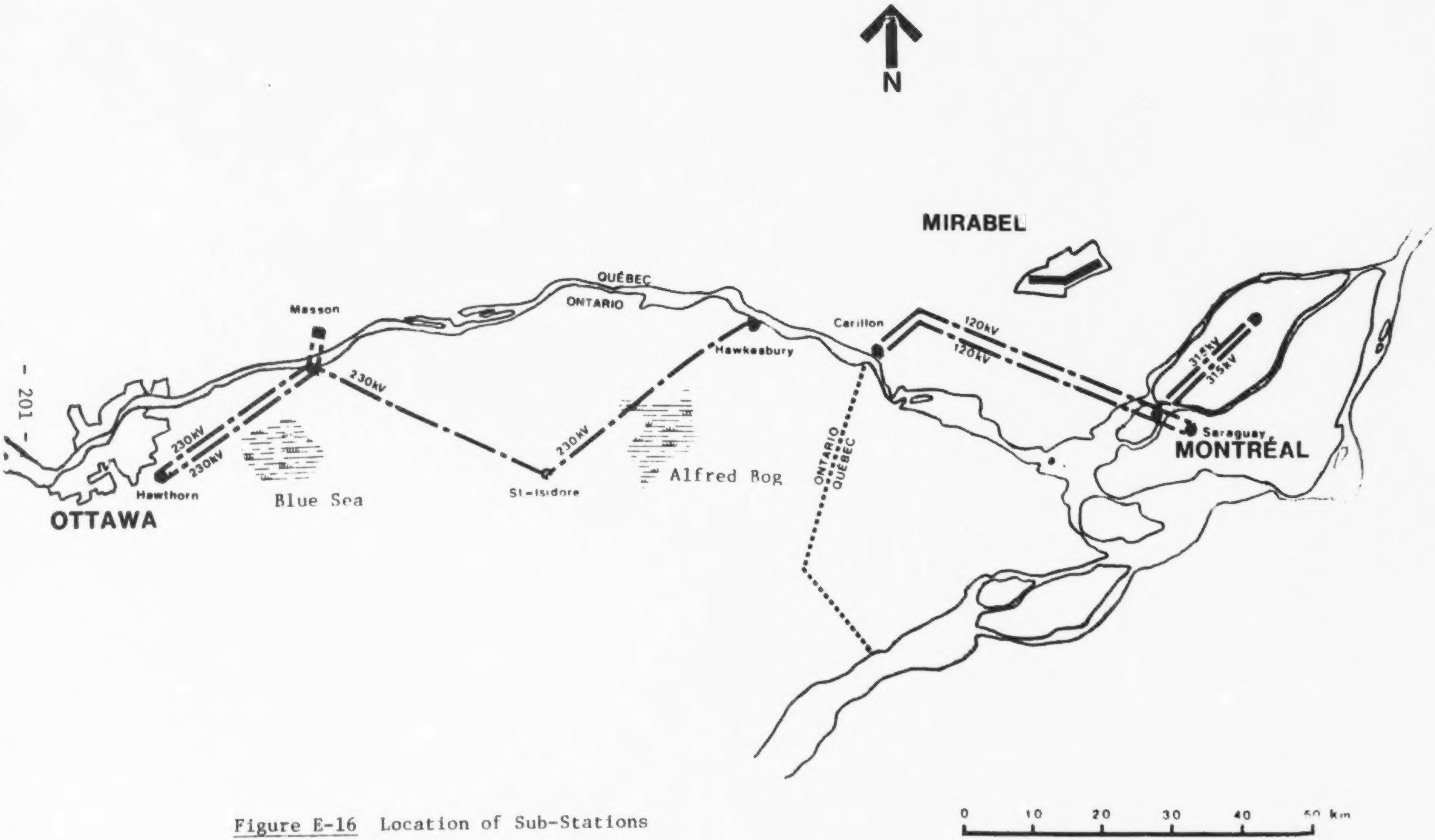

N
MIRABEL
QUÉBEC
ONTARIO
Masson
Carillon
120kV
120kV
315kV
315kV
Seraguay
MONTRÉAL
Hawkesbury
230kV
230kV
230kV
230kV
ONTARIO
QUÉBEC
Hawthorn
OTTAWA
Blue Sea
St-Isidore
Alfred Bog
0
10
20
30
40
50 km

Figure E-16 Location of Sub-Stations

E.7.3 Equipment Sizing

The selection of substation transformer rating is fairly complex and requires a knowledge of the section load variation with time for a given traffic schedule. For the purposes of this analysis, the rating has been estimated as follows:

- the natural cooled rating of each transformer should be sufficient to supply two trains at normal running speed;

- the forced cooled rating should be sufficient to supply one train starting and one train running at normal speed.

Allowing for a single transformer outage, the above considerations result in a requirement for two 6/8/10 MVA transformers at each feeder point.

However, for the 230 kV transformers, the suppliers may find it more appropriate to provide larger units of, say, 25 MVA. Even if this were done, two transformers per site would still be required for redundancy.

Circuit breaker current ratings follow from the selected transformer size. Interrupting ratings are dependent on the supply utility fault level and the supply transformer impedance.

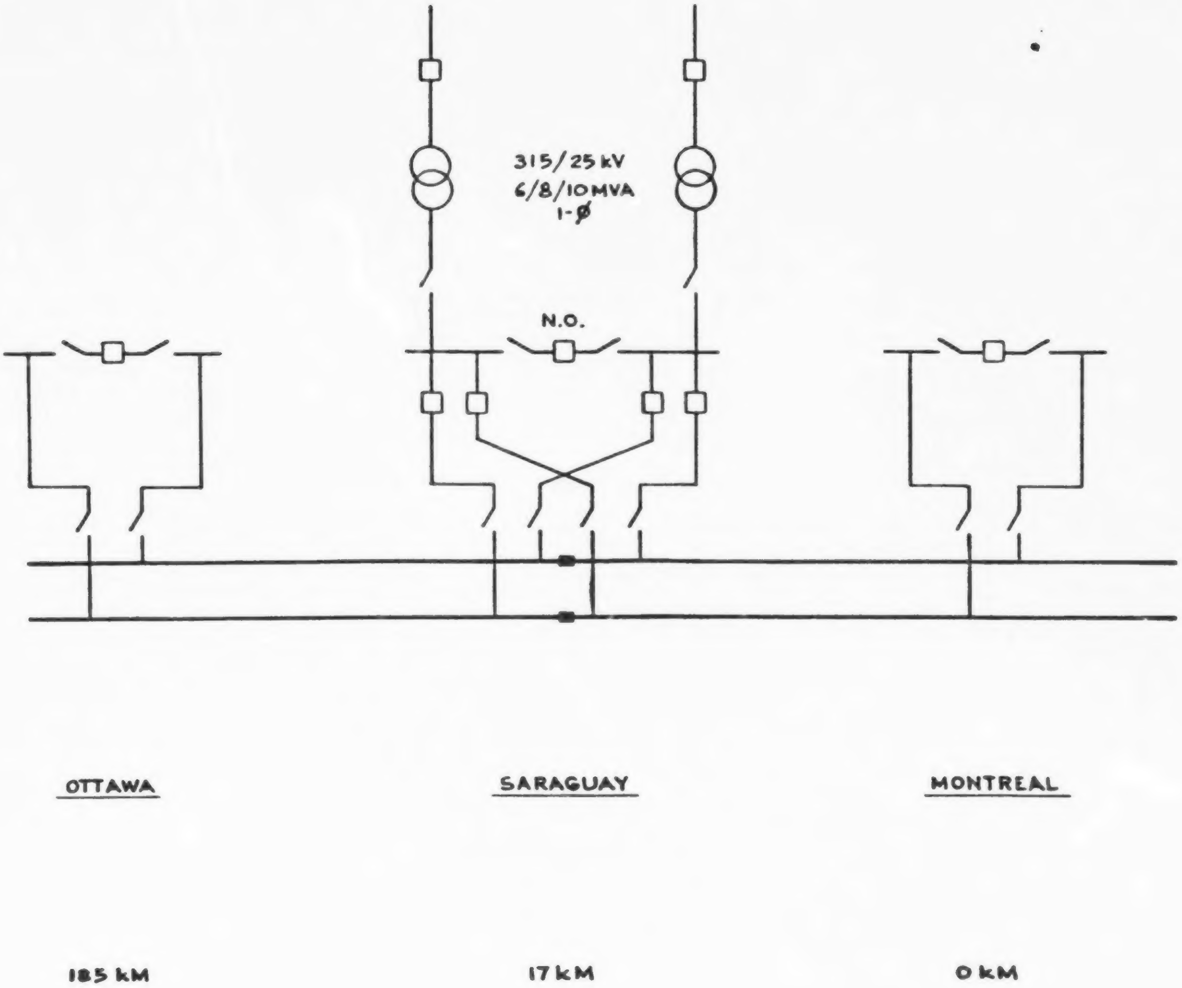
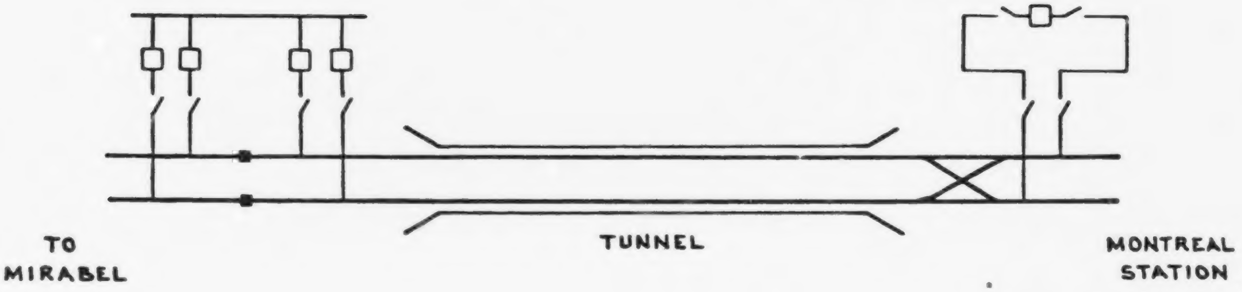
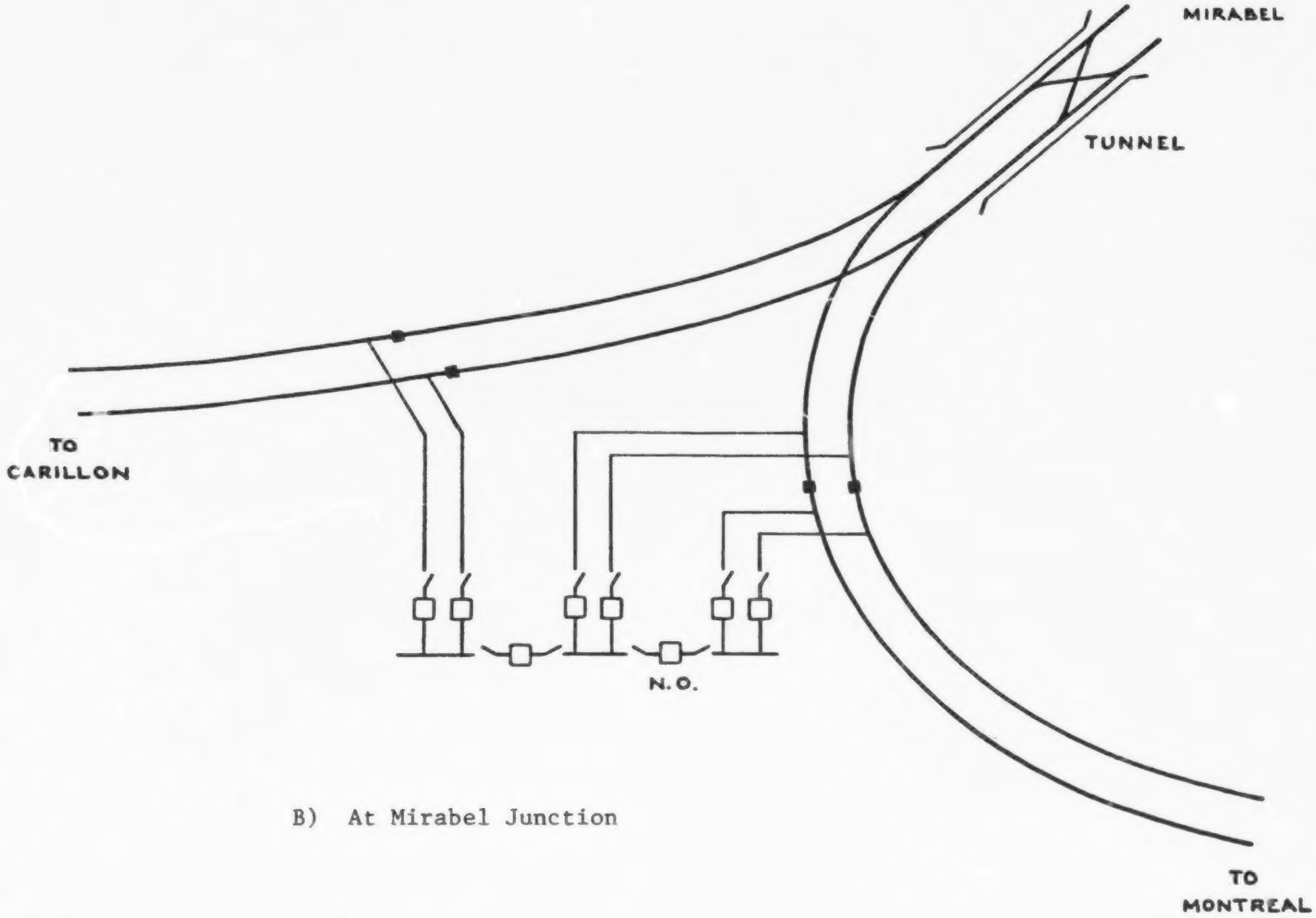

315/25 kV
6/8/10 MVA
1-ø
N.O.
OTTAWA
SARAGUAY
MONTREAL
185 kM
17 kM
0 kM

Figure E-17 Schematic Single Line Diagram of Power Supply and Catenary


TO MIRABEL
TUNNEL
MONTREAL STATION

A) Near Mount Royal Tunnel


MIRABEL
TUNNEL
TO CARILLON
N.O.
TO MONTREAL

B) At Mirabel Junction

Figure E-18 Catenary Switching Arrangement

E.8 Power Distribution Equipment

So as to provide complementary information to Sub-section 5.8.2, this section of Appendix E gives a brief description of the catenary design envisioned for the Rail system.

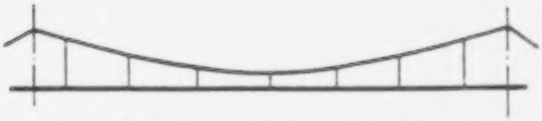
Of the various classical catenary designs, a Y-suspension (Type 5, in Figure E-19) appears the most appropriate for the application: numerous trials have demonstrated that, with spans of 63 m and a Y-height of 10 m, this type of catenary offers very good performance at train speeds up to 225 km/h even under Canadian climatic conditions. Furthermore, by carefully selecting the design parameters (Y-height at 12 m, tension at 11,7 kN, initial contact wire sag of 6 cm), this catenary could eventually be used for speeds approaching 300 km/h. This would give very comfortable margins at the speed envisioned and offer significant development potential.

This contact wire would be a 4/0 notched solid copper wire and the carrier, a 4/0 copper-copperweld type as seen in Figure E-20. An automatic tension apparatus using counterweights, such as that shown in Figure E-21, could be used.

In the tunnel, the catenary would be suspended from the top using consoles anchored in the rock. Figure E-22 shows a typical arrangement in an "ideal" tunnel. It is known that the Mount Royal tunnel offers sufficient clearances for conventional coaches with a 25 kV catenary.

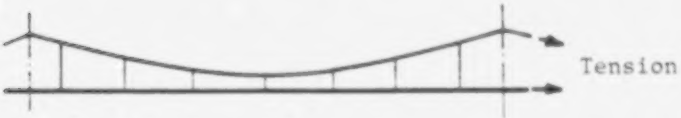
Outside the tunnel and out to Deux-Montagnes, the catenary would be suspended from a structure spanning all tracks as shown in Figure E-23.

Elsewhere, where only two tracks are electrified, a more simple arrangement would be used using either one series of poles mounted centrally or two series of poles mounted laterally as seen in Figure E-24. These steel or concrete poles would be either bolted on or anchored in a concrete foundation. Given the nature of the sub-soil, a forentaken using spread excentric footings as shown in Figure E-25 could often be necessary.



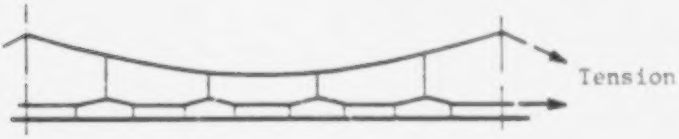
Light Catenary without Tension

TYPE 1



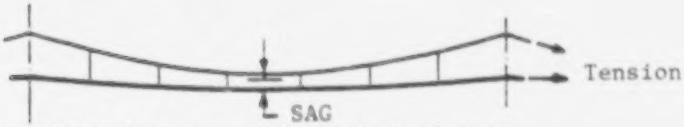
Light Catenary with Tension

TYPE 2



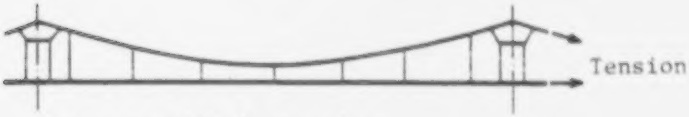
Compound Catenary

TYPE 3


Tension
SAG

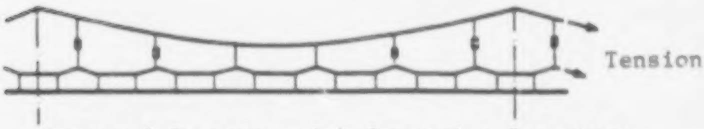
Light Catenary with Optimized Sag

TYPE 4



Catenary with Suspension

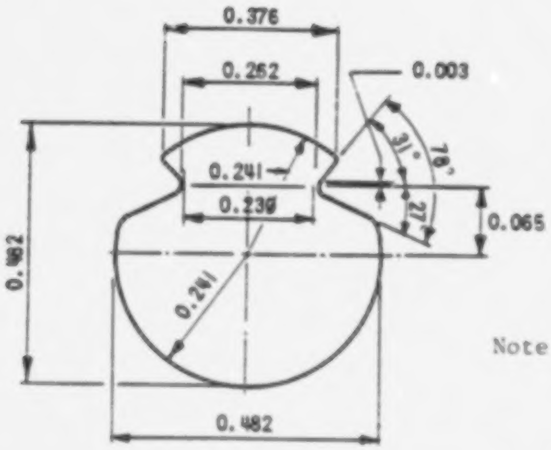
TYPE 5



Compound Catenary with Composite Structure

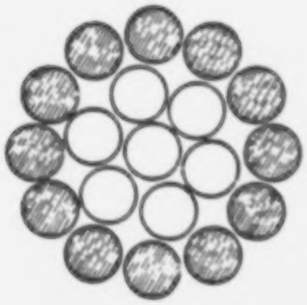
TYPE 6

Figure E-19 Major Catenary Types for a 25 kV System


0.376
0.262
0.003
31°
78°
0.241
0.230
27°
0.065
0.482
0.241
0.482

Note: Dimensions in inches

Contact Wire
4/0 Notched Solid Cooper



Carrier Cable
4/0 Copper - Copperweld

Figure E-20 Conductor Sections for Rail Catenary

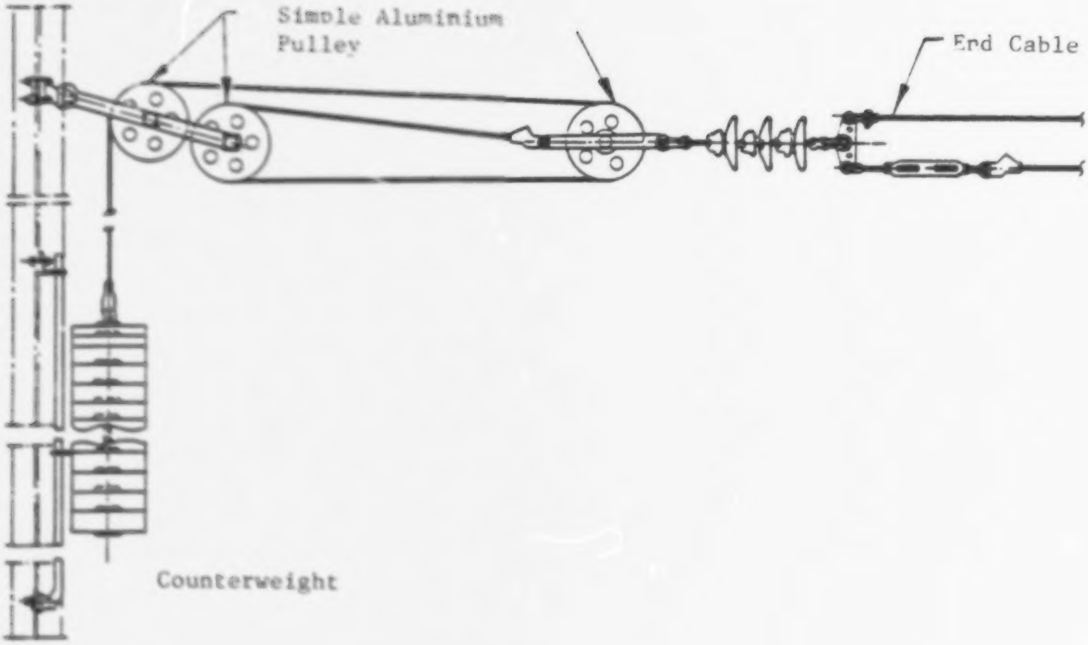
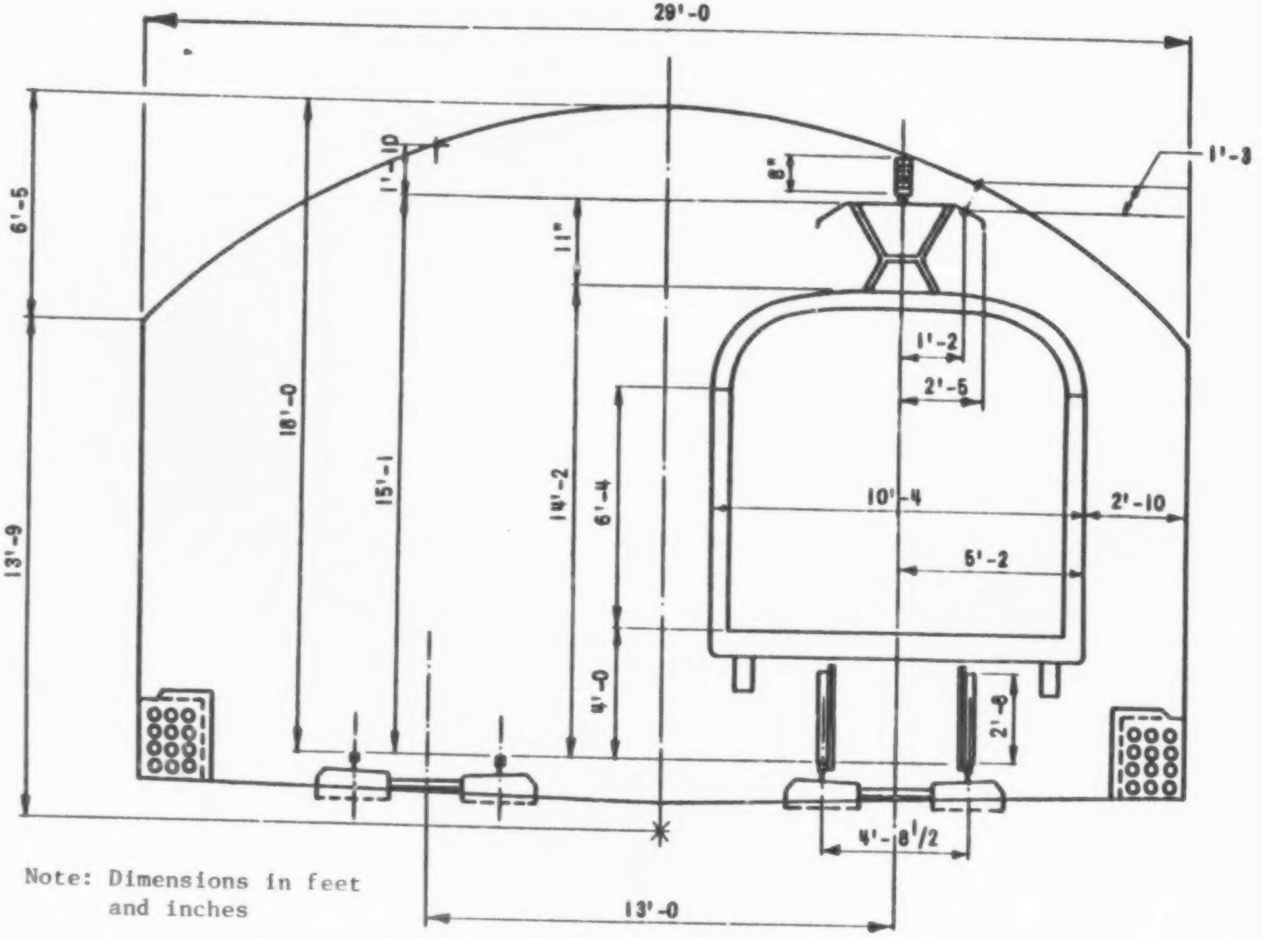

Simple Aluminium Pulley
End Cable
Counterweight

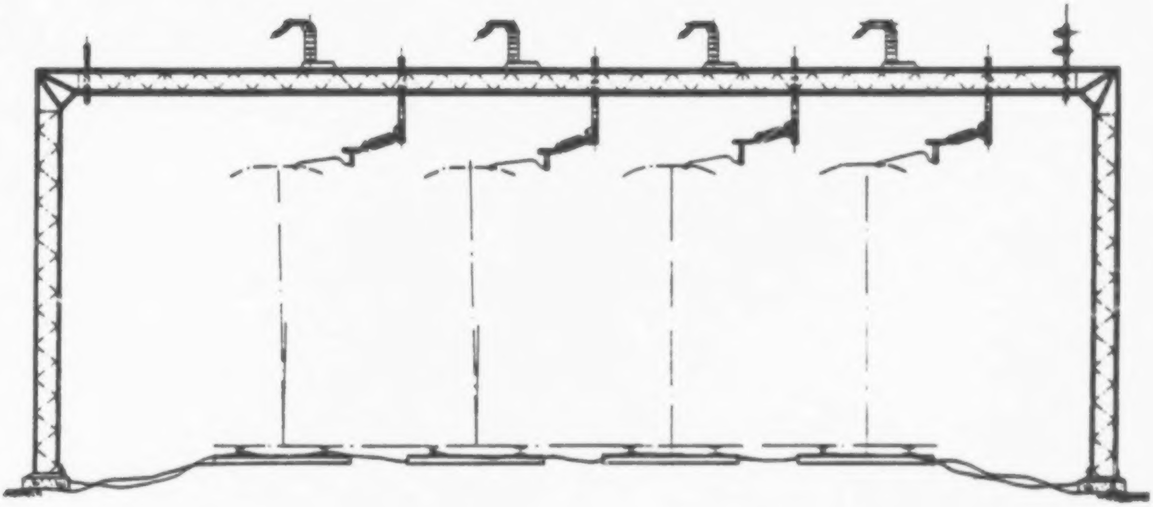
Figure E-21 Automatic Tension Regulation System


29'-0
6'-5
13'-9
18'-0
1'-10
15'-1
11"
14'-2
6'-4
4'-0
8"
1'-3
1'-2
2'-5
10'-4
2'-10
5'-2
2'-8
4'-8 1/2
13'-0

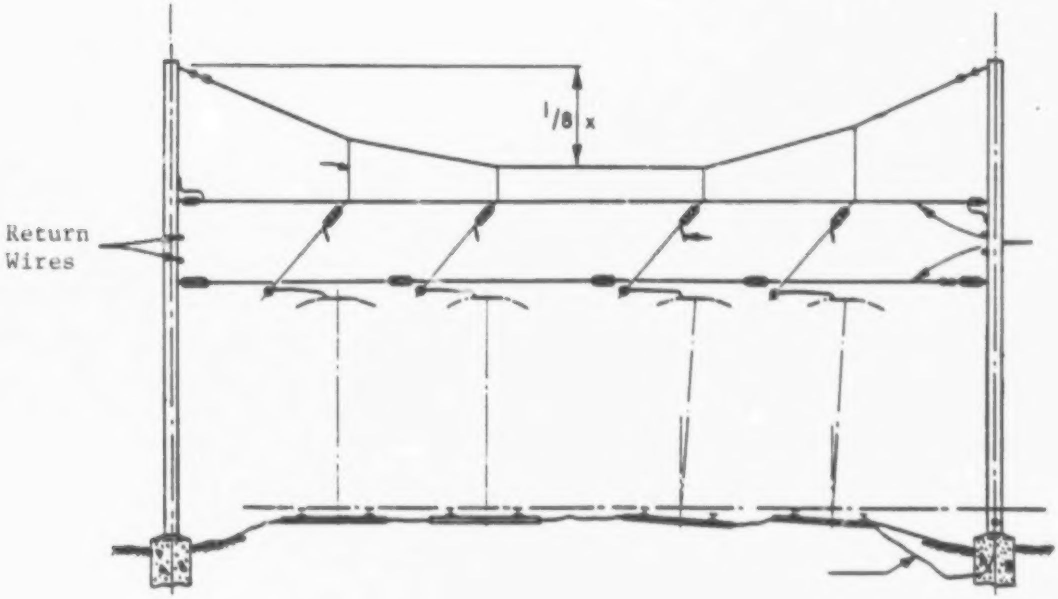
Note: Dimensions in feet
and inches

Clearance between Tracks and Car - Dimensions not applicable to the Rail System

Figure E-22 Typical Catenary Suspension in Tunnel

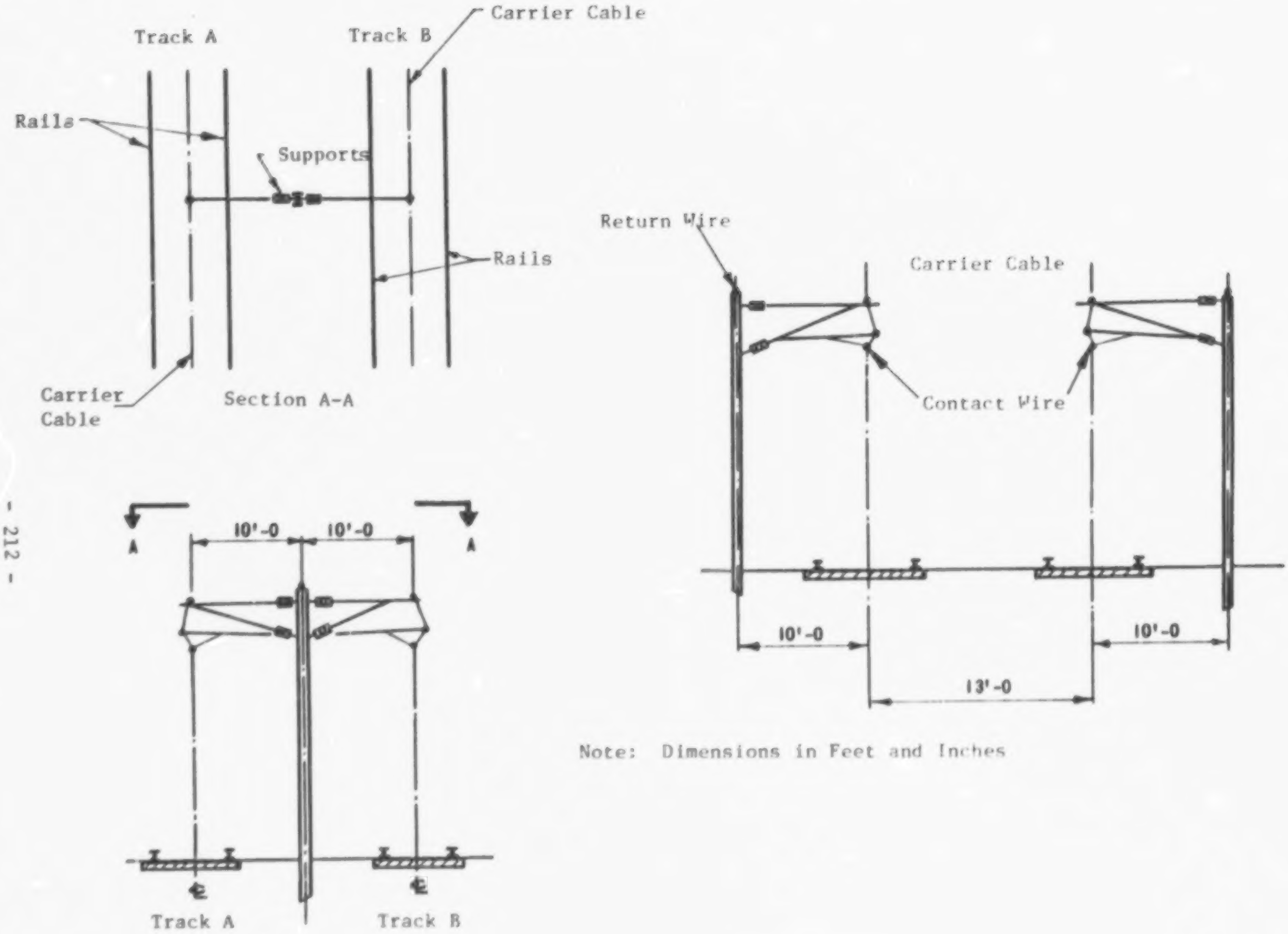


Rigid Frame


1/8 x
Return Wires

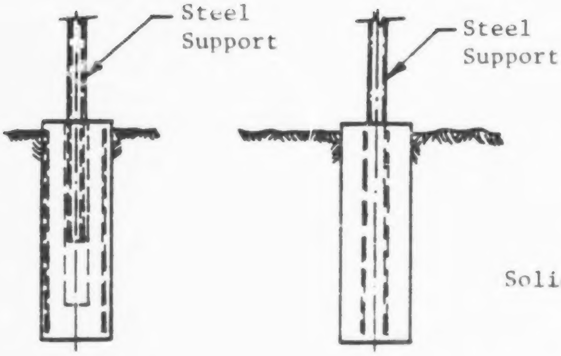
Flexible Structure

Figure E-23 Structures for Catenary Suspension over Multiple Tracks

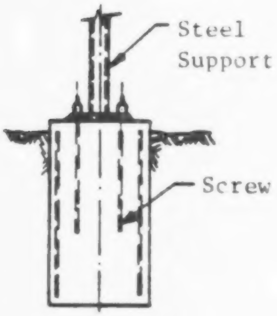

Track A
Track B
Carrier Cable
Rails
Supports
Rails
Carrier Cable
Section A-A
A
A
10'-0
10'-0
℄
℄
Track A
Track B
Return Wire
Carrier Cable
Contact Wire
10'-0
13'-0
10'-0

Note: Dimensions in Feet and Inches

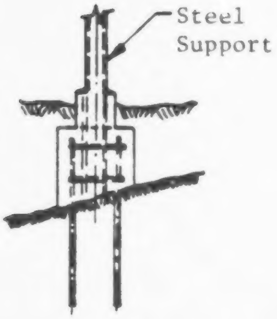
Figure E-24 Catenary Support Systems for Two Tracks


Steel Support
Steel Support

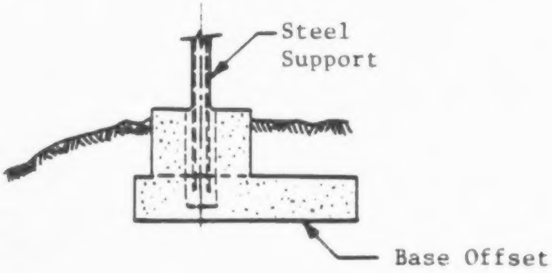
Solid Cement Foundations


Steel Support
Screw

Concrete Foundation with Anchor Bolts


Steel Support

Foundation in Rock


Steel Support
Base Offset

Counterweight Spread Footing Foundation

Figure E-25 Typical Catenary Support Foundations

E.9 Command and Control Equipment

Railway signalling was developed to protect trains from each other at junction points and to route trains through these points to their desired destinations. Switches and signals were initially operated by pulling wires and later by pushing and pulling pipes. As employees could make mistakes, mechanical means were developed to force certain sequences of events and to prevent incorrect and unsafe situations from occuring. The pipes of cables were interlocked in a mechanical frame and from this came the railway term of "interlockings".

There still remained the problem of controlling trains between thse junction points and this introduced "intermediate" or "approach" signals. Mechanical interlockings became very large and complex as many innovations were developed to improve safety and increase operational flexibility.

In the second quarter of the 20th century, the railway signal relay was perfected to a degree such that it was considered that it could be used in properly-designed circuits to provide full safety and flexibility and could thus be used instead of mechanical interlocking frames. This revolutionized railway signalling, led to improved safety and it now became possible to control locations from distant points. In North America with its scattered communities spread over hundreds of miles, the development of Centralized Traffic Control systems grew rapidly.

The initial steps from mechanical interlocking to all-relay interlockings were slow to proceed: extreme caution was exercised in phasing them in, as lives were depending on the new technology.

In the third quarter of this century, new technology emerged: solid state electronics. The introduction of this technology into the supervising control portion of railway signalling grew quickly. However, in the safety control networks, as with the change from mechanical to relay control, the introduction has been cautions and necessarily slow.

Today the railways of the world are beginning to accept solid state electronics and almost accepting microprocessors into safety networks. The breakout into this new technology is forthcoming; whether it will grow quickly now, or ten years from now is unknown. Mistakes in safety networks must not be made, so the growth could be slow for some years to come, but it is going to happen.

When considering a railway that should be implemented in 1991 as in this study, it can be expected that, except for wayside devices such as power-operated switch machines, solid state technology will be used throughout. Indeed, every one of these elements is now in use or in the final stages of testing leading to acceptance as a safe and reliable technique generally available to railway signalling.

As these systems are not yet in day-to-day use, however, the signalling system definition must unfortunably still be based on conventional techniques. To marrow the gap between the technology now used and that which would be used, the definition and costing will be based on one of the most up-to-date systems, that of the French TGV, on which a very substantial amount of documentation is readily available.

E.9.1 Control Center

Montreal - Mirabel - Ottawa HSR operations will be directed from a control center probably located around Deux-Montagnes. That building would house the central functions for signal, power distribution, communication and train operation.

Information for management will be stored and processed by a computerized management information systems (MIS): normal train schedules, alternative schedules (to be implemented should normal schedules be interrupted for any reason), scheduled and unscheduled track and power maintenance requirements and, of course, a great deal of other related information.

In the control center, a train control operations room will house a signal control and indication panel. It will receive from (and deliver to) it field signals commands, indications and control information.

Computers will handle this system in response to information from the field and in response to inputs from the MIS computer (schedules, etc.) and from the operator in charge of the traffic flow.

Therefore a computer (with back-up protection) will handle the train operation and interface with the control console push-buttons, levers and indication lights and with its MIS computer.

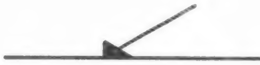
The control panel will contain, as a minimum, the following functions:

- show the location and direction of all trains in 5 km sections (maximum), using assigned train identification numbers;

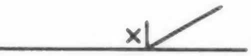
- show the routes established, the position of all switches and the state of the signals at each controlled point;

- establish routes for trains through the field control stations both automatically or by normal intervention by the operator;

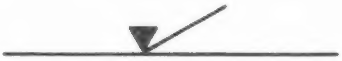
- various alarms will be given by lights and bells in response to specific field conditions such as schedules not being kept, signal problems, power malfunctions, etc.;



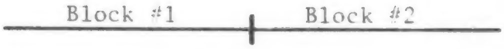
Power Switch activated from central control



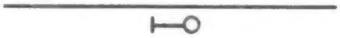
Hand throwm(manual) switch, not electrically locked, activates signal system



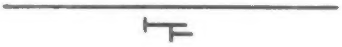
Hand throwm(manual) switch, electrically locked, activates signal system



Designates end of or separation between two blocks (in regular signalling, designates insulated joint between two track circuits)



Designates a signal at power switch locations (controlled locations) which would permit train movements, through the controlled point, should the on-board engine equipment fail



Conventional signal

Figure E-26 Symbols used on Signal Plans for Rail

The operator's function will be to monitor the operation, intervening when required in response to schedule changes, various alarms, work forces requirements. The video units will display, on request, information from the MIS computer required by the operator - schedules, crew consists, and many other operating information. The recommended alternate action may be displayed on the Video screen concerning, schedules, power supply, etc.

The HSR control panel will control the Rail system from Ottawa Station to km 5,4 which is the junction with CN tracks. Although HSR control on on-board equipment will extend into Central Station the wayside signals from km 5,4 to Central Station will be under the control of CN operations.

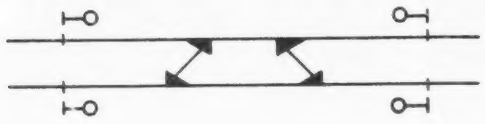
Each location ("interlocking") will receive commands from the signal control panel and will process and send information to that panel concerning the position of switches, location of trains, power supply, route selections, etc.

The communication link between the field and the office will be a high speed solid state system passing information between it control office computer and the field location computers or microprocessors.

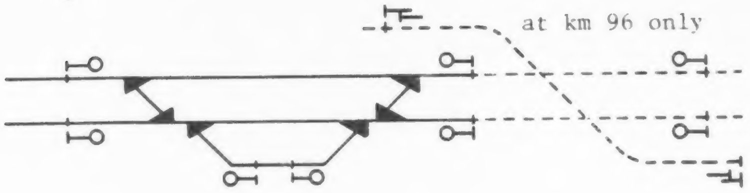
E.9.2 Wayside Equipment - Interlockings

Each controlled point or interlocking will contain remotely-controlled power switch machines which will move and lock the switch points and detect their position. These switches will be equipped with snow clearing apparatus that will be started automatically in response to atmospheric conditions or by direct remote control from Central control.

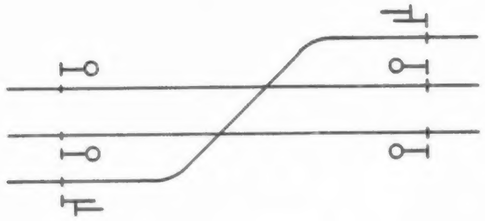
When approaching high-speed switches that are in the reverse position, HSR trains will be controlled by the engineman, in response to cab signal indications to maintain a reduced speed of 160 km/h.



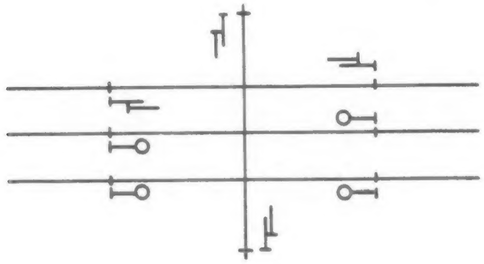
a) Double Crossover (km 16, 30, 75, 117, 161, 184)



b) Double Crossover with Siding (km 96, 140)



c) Two-Track Crossing (km 94, 152)



d) Three-Track Crossing (Hawkesbury Spur)

Figure E-27 Wayside Equipment at Typical Interlockings

Power-operated switches to storage sidings will permit train speeds of 50 km/h. In this case, the engineman, in response to cab signal indications, will approach the interlocking prepared to stop. He can then proceed by authority for ground signal into the storage siding.

At location km 11+400 the power-operated switches are used to route CN trains at a maximum speed of 50 km/h across the HSR line. A special extra lever manipulation at the signal control panel is required to position the switches for a CN train to enter on leave the HSR tracks.

Each controlled point or interlocking will be surrounded by dwarf signals which will display an indication for trains to proceed, to take a diverging route (into a storage siding) or to stop.

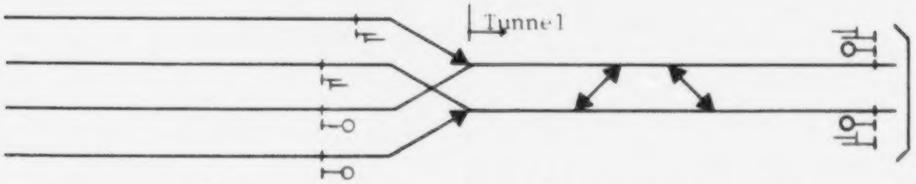
The purpose of these signals is to indicate to the crews of trains without cab signal or with a defective cab signal the locomotive has failed (or does not) that it is safe to move over the power switches in the interlocking. Standard rules and instructions will govern the train movements beyond the interlocking limits.

E.9.3 Wayside Equipment - Intermediate Areas

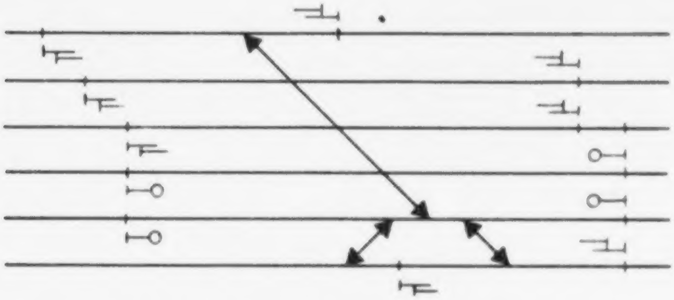
The area between interlockings will be divided into "block" sections of approximately 2000 m length. The exact length will depend on train braking characteristics, local grades and permanent speed restrictions.

The block section will be a track circuit which will detect and report to the signal safety system:

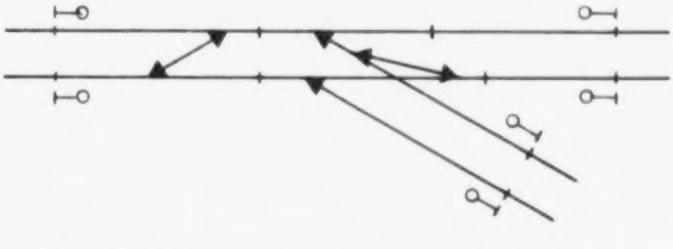
- the presence of a train;
- that the track is continuous;
- that switches in the block are electrically locked in the proper positions.



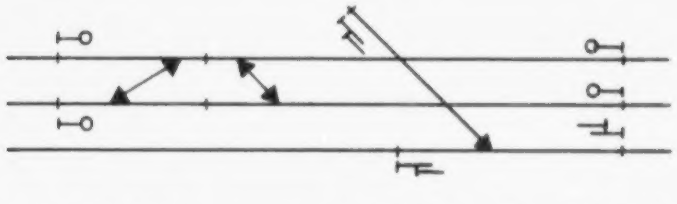
a) Entrence to Mount Royal Tunnel (km 5 + 400)



b) Cartierville Spur Crossover (km 11 + 400)



c) Mirabel Junction (km 45)



d) Double Crossover with Crossing (km 118, 184)

Figure E-28 Wayside Equipment at Special Interlockings

The track circuit will also transmit to the on-board equipment information that, once processed on-board, will result in cab signal displays, train speed enforcement, etc.

The solid-state-electronics track circuits will be jointless to avoid that insulated joints cut the welded rail, and will transmit six different speed commands to the propulsion control equipment. These commands will be such that a HSR train travelling at maximum speed will be brought to a reduced speed and if necessary to a final stop smoothly and safely by the engineman.

Track circuits will be immune to electrical interferences from traction power and all other electrical sources such as power transmission lines and lightning. There will be no conventional type wayside signals. Rather, there will be a reflectoring marker at each block end.

The block and the signal system will provide full train operation in both directions on each of the two tracks. Between Central Station and km 5,4, the CN signal system will remain and will govern train operations. Superimposed over this will be the HSR block system.

In Central Station, the tracks assigned to HSR will be equipped with special apparatus to checkout the on-board signalling equipment to determine that it is working correctly. These tests will be performed daily on each train before its first departure. Similar equipment will be provided at Mirabel and Ottawa.

E.9.4 On-Board Equipment

One of two methods for bringing a train to a safe controlled speed and to stop will be used:

- the engineman would control his train according to information displayed in the cab. Should he fail to reduce speed as required and be over speed at the next bock the train would automatically be brought to an emergency full stop. This is the method used by the TGV and assumed in this study;

- an alternate method, worthy of consideration in a more detailed study, is one where the train braking characteristics are used to produce a braking profile. When the automatic equipment ensures that be control the train at a reducing speed below that of the brake profile. With the rapid development in technology the method may become economically attractive by the time this project is implemented.

Signal blocks (length, spacing, information) and on-board control equipment make both of the above techniques safe.

On-board computing equipment will receive commands from the track circuits which will be interpreted and displayed as commands and information to the engineman. Information displayed would be similar to that of the TGV: actual train speed, permissible track speed, permissible train speed, permissible train speed at which to enter the next block.

Automatic control will enforce compliance by the engineman to reduce speed and/or stop. Failure to do so and/or driving the consist at a speed exceeding the local control speed will cause the train to come to a full stop or to a reduced speed by triggering an automatic application of the emergency brake.

The on-board signalling equipment will be automatically checked daily to see that it is functioning correctly, upon the first departure at Montreal, Mirabel and Ottawa. Should the equipment fail enroute, an emergency release is available. The train would then be handled according to special rules and instructions preparing to stop at the next interlocking.

E.9.5 Equipment Requirements

The requirements for central, wayside, and on-board command and control equipment, which were summarized in Table 5-9, will now be given in detail. The locations of the major control points are shown in the following portions of the track layout, Figure E-8:

Page 1	0+00 to 13+00
Page 2	16+00 to 18+00
Page 4	38+00 to 44+00
Page 6	72+00 to 75+00
Page 7	92+00 to 95+00
	101+00 to 103+00
Page 8	116+00 to 119+00
Page 9	136+00 to 139+00
Page 10	150+00 to 155+00
	160+00 to 162+00
Page	180+00 to 185+00

Based on these functional arrangements and on the symbols explained in Figure E-26, the wayside equipment at interlockings is as shown in Figure E-27 for typical interlockings and in Figure E-28 for special interlockings.

Table E-27

AAR Counts for Typical Interlockings

Item	Unit AAR Points	Double Crossover		Double Crossover with Siding		Two Tracks level Crossing		Three Tracks level Crossing	
		Number	Points	Number	Points	Number	Points	Number	Points
Power Turnouts	12	4	48	6	72	0	0	0	0
Signals	14	4	56	6	84	4	56	4	56
Traffic Locking	2	4	8	4	8	4	8	4	8
Approach Locking	2	4	8	4	8	4	8	4	8
Track Circuits	6	4	24	6	36	3	18	4	24
Code Units	10	2	20	2	20	1	10	1	10
CN Signals	6	0	0	1	6	2	12	4	24
Total per Interlocking	-	-	164	-	234	-	112	-	130
Number of Interlockings	-	4	-	2	-	2	-	1	-
Number of Points	-	-	656	-	468	-	224	-	130

E.9.6 Capital Cost Estimates

The cost of wayside equipment was estimated using the AAR point count method. This method consists of assigning a number of "points" to each function, totaling the nomber of points and assigning a value to each point. This method is the most frequently used by Canadian Railroads.

There is a problem, however, associated with the choice of a suitable monetary value for the unit AAR point. This problem is relatively easy to resolve in conventional applications, as there are usually recent actual cost references.

Such is not the case here, however, as the signalling system envisioned is significantly more performing and more complex than these normally installed on Canadian railways. The choice of suitable cost for the unit AAR unit becomes crucial.

Furtunately, a very substantial amount of information was available to resolve this dilemna, especially on the Paris-Lyon TGV line. This line was dissected to establish its number of AAR units and based on its published signalling design and cost, a unit AAR value could be derived, which was then checked for applicability to Canadian conditions. This is how the unit cost of $11 000 was derived.

The quantities, summarized in Tables E-27 for typical interlockings and E-28 for special interlockings, were derived from Figure E-27 and E-28, respectively. The estimated capital costs are given in Table E-29.

Table E-28

AAR Counts for Special Interlockings

Item	Unit AAR Points	Tunnel Exit		Cartierville Spur		Mirabel Junction		Ottawa Station	
		Number	Points	Number	Points	Number	Points	Number	Points
Power Turnouts	12	6	72	4	48	8	96	5	60
Signals	14	4	56	4	56	6	84	4	56
Traffic Locking	2	6	12	4	8	6	12	4	8
Approach Locking	2	6	12	4	8	6	12	2	4
Track Circuit	6	4	24	6	36	6	36	6	36
Code Units	10	2	20	1	10	3	30	2	20
CN Signals	6	6*	36	7	42	0	0	3	18
Total per Interlocking	-	-	232	-	208	-	270	-	206

* 4 signals equivalent to AAR count for 6 signals.

Table E-29

Cost Breakdown for Signalling Sub-System

Item	Number	AAR Count		Cost
		Unit	Total	
Typical Interlockings	9	-	1 475	$ 16,3 M
Special Interlockings	4	-	916	$ 10,1 M
Electric Locks	10	4	40	$ 0,4 M
Signal Blocks	175	4	700	$ 7,7 M
Total AAR Point Count @ $11 000 / point			3 134	$ 34,5 M
Hot Journal Detectors 10 @ $37 800 =				$ 0,4 M
		Total Wayside Equipment		$ 34,9 M
Control Center Equipment		Total Central Equipment		$ 4,5 M

F. MAGLEV SYSTEM DOCUMENTATION

This appendix provides complementary information and supporting material on the definition of the Maglev system presented in Chapter 6. Material is presented herein in the same order as in Chapter 6, but there is not necessarily a one-to-one correspondance between sections and sub-sections of Chapter 6 and those of this appendix.

F.1 Line Capacity

This section corresponds to Section 6.3 and is subdivided into four successive sub-sections as follows: capacity requirement, load factor and capacity adjustment, trip time, schedule and consist assignment.

F.1.1 Capacity Requirement

Columns 4 and 5 of Table F-1 show the traffic loads that will serve a basis for defining the Maglev system.

These traffic loads were calculated from year by year traffic forecasts on the West Island to Mirabel link, (which is the most heavily loaded portion of the route). These year-by-year traffic forecasts are shown in Columns 2 and 3 of Table F-1 and were taken from (and interpolated as required) data presented in Table 1-15.

To derive traffic loads from forecasts of annual traffic, a number of assumptions had to be made. First, it was assumed that directional traffic, measured in one-way trips, was exactly half of the expected total annual (bi-directional) traffic shown in Table 1-15.

Then, daily directional traffic was estimated by dividing annual directional traffic by 300. This procedure yields a better estimate for a typical weekday than dividing by 365.

To reflect the significant concentration of trips that will occur around the beginning and around the end of the normal 9-to-5 business day, it was assumed that 33% of daily passenger departures would take place in each of two peak-hour periods lasting slightly in excess of 2 hours.

As the annual traffic, this peak-period traffic load varies slightly between the various links of the route, reflecting the geographic distribution of trip ends according to passenger origin and destination. As the most heavily-loaded portion of the route is the link between the suburban station in the West Island and Mirabel Airport, the peak-period directional traffic load along that link indeed becomes the line capacity requirement for defining the Maglev system.

F.1.2 Load Factor and Capacity Adjustment

The basic Maglev consist, as defined in Chapter 2, is a bi-directional vehicle with a total capacity of 192 seats. The capacity of the basic consist can be increased by the introduction of one to four intermediate sections between the two end sections that constitute the basic vehicle; each basic section offers 96 seats also.

Based on a 45-min headway and a 2h15 min duration, the peak period capacity with a basic two-section vehicle is 768 seats; it increases as follows with the successive addition of 1, 2 and 3 intermediate sections: 1152, 1536, 1920.

As the load factor reaches 90% for the maximum traffic load in 1992, the capacity must be increased by the addition of one intermediate section in each consist. So the load factor is lower in 1993 and picks up again as the traffic continues to increase with time. The same happers in 1998.

The evolution of load factor as traffic increases with time is shown in Columns 7 and 8 of Table F-1 and illustrated in Figure 6-1.

Table F-1

Traffic Forecasts, Capacity, and Load Factor for Maglev

Year	Annual Traffic Forecast[1] (1000 person-trips, bi-directional)		Peak-Period Traffic[2] (Person-trips, directional)		Capacity[3] (seats/train)	Capacity (seats/peak period)	Load Factor (%)	
	Minimum	Maximum	Minimum	Maximum			Minimum	Maximum
1991	1 453	1 816	807	1 009	288	1 152	70	87
1992	1 505	1 873	836	1 040	288	1 152	72	90
1993	1 559	1 943	866	1 079	384	1 536	56	70
1994	1 614	2 016	897	1 121	384	1 536	58	73
1995	1 674	2 091	930	1 162	384	1 536	61	76
1996	1 735	2 171	964	1 206	384	1 536	63	79
1997	1 797	2 252	991	1 251	384	1 536	65	81
1998	1 864	2 338	1 035	1 299	384	1 536	67	85
1999	1 934	2 428	1 074	1 349	480	1 920	56	70
2000	2 004	2 520	1 113	1 400	480	1 920	58	73
2001	2 078	2 616	1 155	1 454	480	1 920	60	76
2002	2 128	2 680	1 183	1 489	480	1 920	62	78
2003	2 159	2 720	1 200	1 511	576	1 920	63	79
2004	2 179	2 747	1 211	1 526	576	1 920	63	79
2005	2 193	2 765	1 218	1 537	576	1 920	63	80
2006	2 200	2 775	1 223	1 542	576	1 920	64	80
2007	2 206	2 781	1 225	1 545	576	1 920	64	80
2008	2 208	2 785	1 226	1 548	576	1 920	64	81
2009	2 211	2 788	1 228	1 549	576	1 920	64	81
2010	2 212	2 789	1 228	1 550	576	1 920	64	81
2011	2 212	2 790	1 228	1 550	576	1 920	64	81

Notes:

1. Thousand person-trips per year (bi-directional) on the West Island to Mirabel link. This data is taken from Table 1-15 for years 1991, 1996, 2001, 2006, and 2011, and interpolated for intermediate years.
2. Thirty three per cent of the annual daily traffic, which is 1/300 of the annual directional traffic.
3. At 96 seats for every section, trains are made up of 3, 4, or 5 sections, successively (Figure 6-1).

F.1.3 Trip Time

Trip time between Montreal, Mirabel and Ottawa, was calculated using the Maglev route characteristics described and illustrated in Appendix C and summarized in Table F-2, together with the performance parameters given for the vehicle in Section F.2. Other assumptions used in the simulation that served as a basis for this calculation are:

- station dwell time of 90 s;
- operating speed presumed never to exceed 200 km/h in urban areas;
- speed restrictions through curves based on a maximum lateral acceleration of 1,0 m/s^2 which corresponds to the comfort limit with a 12° superelevation;
- push-pull operation and delay-free operating practice.

The results of the simulation are illustrated in Figure F-1.

The speed profile in Figure F-1 shows theoretical running times, for which the most significant results are summarized in Table F-3.

To obtain actual travel times from running times, the following must be done:

- add 90 s dwell times at both intermediate stations \
- add 6% of running time as a time margin constituting an operational reserve to compensate for unexpected delays.

Actual travel times for each link are given in Table F-4: total travel time is 46 minutes.

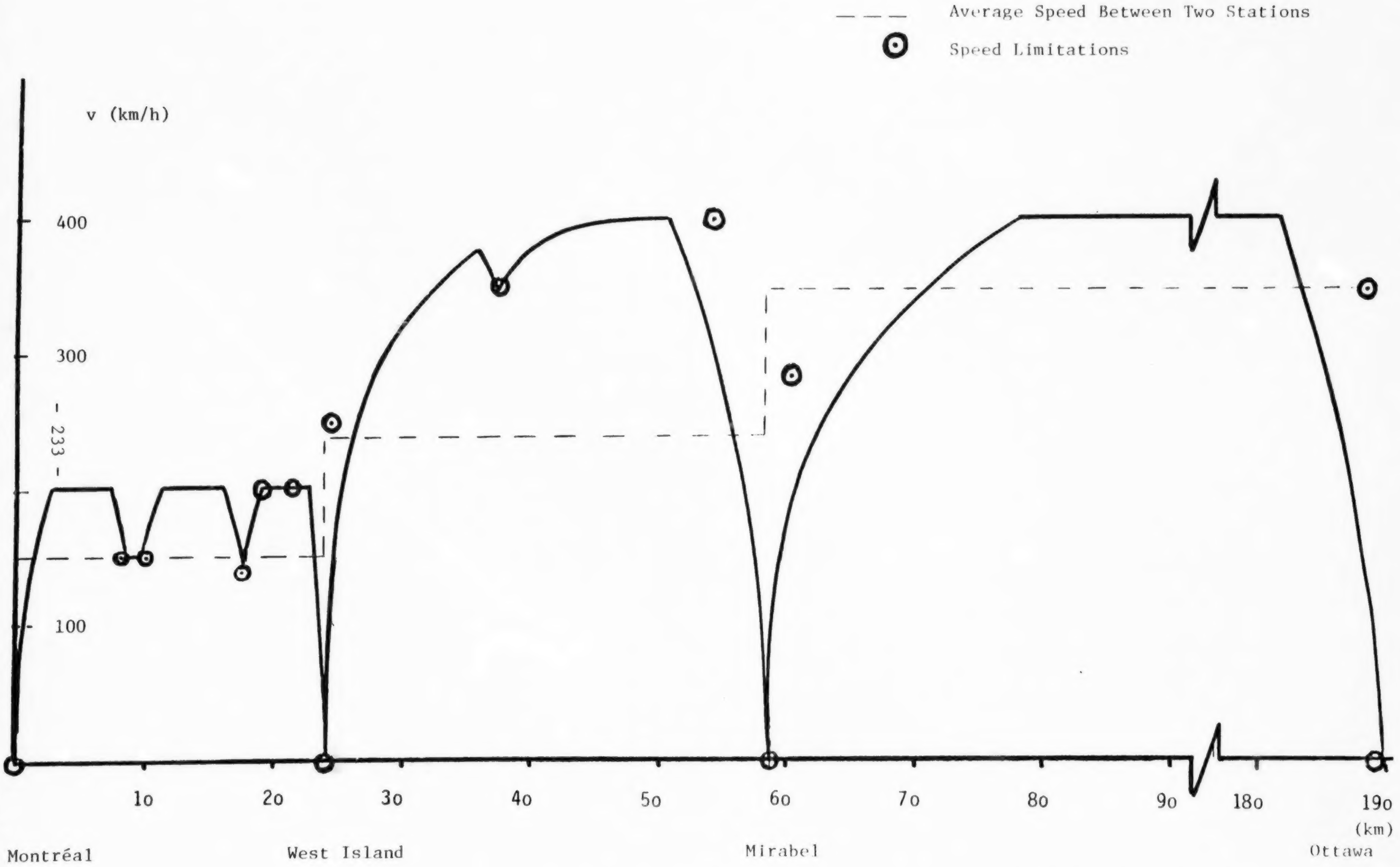


Figure F-1 Maglev Simulated Speed Profile Between Montreal and Ottawa

Table F-2

Maglev Route Characteristics
(Page 1 of 2)

Km from Windsor Station		Route Feature	Maximum speed -km/h	Reason
From	to			
- 175	0	Windsor Station Platform	0	S
0	300	Level Tangent over Railway	200	U
300	2 850	Grade: + 1,4%	200	U
2 850	2 950	Level Tangent over Railway	200	U
2 950	5 800	Grade: - 1,4%	200	U
5 800	7 600	Level Tangent over Railway	200	U
7 600	8 200	Curve Right; Radius: 640 m	150	C
8 200	9 400	Level Tangent over Railway	200	U
9 400	10 000	Curve Left; Radius: 570 m	140	C
10 000	17 500	Level Tangent over Railway	200	U
17 500	17 600	Curve Right; Radius: 563 m	140	C
17 600	18 100	Superimpose Grade: - 1,4%	-	-
18 100	18 200	Grade: - 1,4%	200	U
18 200	18 400	Level Tangent at Grade	200	U
18 400	19 000	Curve Left; Radius: 1 000 m	200	U
		Guideway below Grade	-	-
19 000	19 700	Level Tangent below Grade	200	U
19 700	20 000	Grade: + 0,7%	200	U
20 000	20 250	Grade: + 0,7%	200	U
20 250	21 200	Grade and Curve as below	200	U
21 200	21 650	Curve Right; Radius: 1 000 m	200	U
21 650	23 800	Level Tangent over Railway	200	U
23 800	24 750	Curve Left; Radius: 1 600 m	200	U
		Superimpose Grade: - 0,6%	-	-
24 750	24 925	West Island Station Platform	0	S
24 925	25 100	Curve and Grade as above	200	U
25 100	26 000	Grade as above	200	U
26 000	28 000	Grade: + 0,5%	200	U
28 000	30 000	Level Tangent 5 m above Terrain	400	P
30 000	32 000	Level Tangent 5 m above Terrain	400	P
32 000	35 300	Grade: - 0,33%	400	P
35 300	36 400	Grade: + 0,5%	400	P
36 400	37 300	Superimpose Curve Right; Radius: 3 000 m	350	C
37 300	39 600	Grade: + 0,3%	400	P
39 600	40 000	Grade: + 0,4%	400	P
40 000	42 000	Grade: + 0,4%	400	P
42 000	43 000	Level Tangent 5 m above Terrain	400	P
43 000	45 500	Grade: + 0,8%	400	P
45 500	50 000	Level Tangent 5 m above Terrain	400	P

Table F-2

Maglev Route Characteristics
(Page 2 of 2)

Km from Windsor Station		Route Feature	Maxi-mum speed -km/h	Rea-son
From	to			
50 000	50 300	Level Tangent 5 m above Terrain	400	P
50 300	53 500	Curve Left; Radius: 4 000 m	400	P
53 500	56 300	Curve Continues	400	P
		Clearance diminishes to 0 m	-	-
56 300	57 400	Level Tangent at Grade	400	P
57 400	57 600	Grade: - 1,0% in a Cut	400	P
57 600	57 700	Level Tangent in a Cut	400	P
57 700	57 900	Mirabel Airport Station	0	S
57 900	58 000	Level Tangent in a Cut	400	P
58 000	58 400	Curve Right; Radius: 500 m	130	C
58 400	59 400	Grade: + 0,9%	400	P
59 400	60 000	Level Tangent 5 m above Terrain	400	P
60 000	62 300	Level Tangent 5 m above Terrain	400	P
62 300	63 600	Curve Left; Radius: 1 700 m	-	C
63 600	70 000	Level Tangent 5 m above Terrain	400	P
70 000	80 000	Level Tangent 5 m above Terrain	400	P
80 000	81 400	Level Tangent 5 m above Terrain	400	P
81 400	85 400	Grade: - 0,7%	400	P
85 400	90 000	Grade: + 0,56%	400	P
90 000	90 500	Grade: + 0,56%	400	P
90 500	91 800	Level Tangent 5 m above Terrain	400	P
91 800	94 900	Grade: + 0,6%	400	P
94 900	100 000	Grade: - 0,56%	400	P
100 000	101 000	Grade: - 0,56%	400	P
101 000	110 000	Level Tangent 5 m above Terrain	400	P
110 000	180 000	Level Tangent 5 m above Terrain	400	P
180 000	183 000	Level Tangent besides Railway	400	P
183 000	185 400	Grade: - 0,7%, clearance diminishing	200	U
185 400	187 000	Curve Right; Radius: 3 000 m	200	C
187 000	188 025	Level Tangent at Grade	200	U
188 025	189 010	Curve Left; Radius: 3 000 m	200	U
189 010	189 300	Level Tangent at Grade	200	U
189 300	189 500	Ottawa Terminal	0	S

Notes: 1. "Tangent" includes curves with a radius larger than 4 000 m.
2. "Level" includes curves smaller than ± 0,3%.
3. Key to symbols for speed restrictions:
S= Mandatory Station Stop
U= Urban area
C= Curve
P= Performance Specified

Table F-3

Trip Time Between Montreal, Mirabel, and Ottawa by Maglev

Speed		Trip Link (m)	Time (s)	Cumulative Time (s)	Comments
Beginning	End	From - To			
	0	0,00	0,0	0,0	Windsor Station
0 -	200	0,00 - 2,80	100,8	100,8	Acceleration
200 -	200	2,80 - 6,48	66,2	167,0	Urban Area
200 -	140	6,48 - 7,60	23,7	190,7	Curve
140 -	140	7,60 - 10,00	61,7	252,4	Curve
150 -	200	8,20 - 11,60	69,9	322,3	-
200 -	200	11,60 - 16,58	89,6	411,9	-
200 -	140	16,58 - 17,70	23,7	435,6	-
140 -	200	17,70 - 19,60	40,2	475,8	-
200 -	200	19,60 - 23,50	70,2	546,0	-
200 -	0	23,50 - 25,00	27,0	573,0	-
0 -	0	25,00	90,0	663,0	West Island Station
0 -	350	25,00 - 40,00	154,3	817,3	-
350 -	400	40,00 - 47,30	522,0	1 339,3	-
		- -	-	-	-
400 -	0	49,80 - 57,50	69,3	1 408,6	-
0 -	0	57,50	90,0	1 498,6	Mirabel Airport Station
0 -	400	57,50 - 80,50	207,0	1 705,6	-
400 -	400	80,50 - 181,80	911,7	2 617,3	-
400 -	0	181,80 - 189,50	69,3	2 686,6	-
0		189,50	-	2 700,0	Ottawa Terminal

F.1.4 Schedule and Consist Assignment

Based on a travel time of 45 min and an interval of 45 min, a schedule was calculated.

The results are given in Table F-4, which is the basis for Figure 6-2.

It can be deducted from these results that the service envisioned can be offered by placing only four consists in operation.

Table F-4

Trip and Consist Schedule for Maglev

From Montreal					From Ottawa				
Trip Number	Consist I.D.	Departure Time	Arrival Time	Layoff Time	Trip Number	Conisit I.D.	Departure Time	Arrival Time	Layoff Time
1	M1	6h30	7h15	-	2	M2	6h30	7h15	-
3	M3	7h15	8h00	-	4	M4	7h15	8h00	-
5	M2	8h00	8h45	-	6	M1	8h00	8h45	-
7	M4	8h45	9h30	-	8	M3	8h45	9h30	-
9	M1	9h30	10h15	-	10	M2	9h30	10h15	-
11	M3	11h00	11h45	-	12	M4	11h00	11h45	-
13	M2	12h30	13h15	-	14	M1	12h30	13h15	-
15	M4	13h30	14h15	-	1[illegible]	M3	13h30	14h15	-
17	M1	15h00	15h45	-	18	M2	15h00	15h45	-
19	M3	16h15	17h00	-	20	M4	16h15	17h00	-
21	M2	17h00	17h45	-	22	M1	17h00	17h45	-
23	M4	17h45	18h30	-	24	M3	17h45	18h30	-
25	M1	18h30	19h15	-	26	M2	18h30	19h15	-
27	M3	19h30	20h15	-	28	M4	19h30	20h15	-
29	M2	20h30	21h15	-	30	M1	20h30	21h15	-
31	M4	21h30	22h15	-	32	M3	21h30	22h15	-
33	M1	23h00	23h45	-	34	M4	23h00	23h45	-
35	M3	24h15	1h00	-	36	M2	24h15	1h10	-

Notes:
1. Trip time of 45 min including two station stops of 90 s.
2. Minimum terminal dwell time of 30 min.
3. The next day, consist M2 and M4 start in Montreal, consists M1 and M3 in Ottawa, and the schedule is reversed, but identical in all other respects.

F.2 Vehicle Description and Performance

The basic Maglev consist is a bi-directional two-section vehicle that is 54,2 m long, 3,7 m wide, and has an overall height of 4,2 m with a protrusion above the guideway of 3,2 m. This vehicle offers 192 seats in rows of five (by two and three, Figure F-2) or, exceptionally, four.

F.2.1 Structure and Layout

The structure of the vehicle is monocoque; it consists of a sandwich made of a 80-mm thick core of expanded rigid PVC foam sandwiched between two aluminum sheets with thicknesses of 1,2 mm (outer) and 0,8 mm (inner). These prefabricated and pre-formed sandwich plates are cemented and riveted onto a series of transverse frames made of aluminum profiles (Figure F-3).

Each vehicle section has four double-hinged sliding-plug doors to facilitate passenger flow and double panes made of security glass. At each end is a driver's cockpit that can be reached foom the passenger cabin. It contains all the necessary indications and instruments for monitoring and operating all train systems. Each end of the vehicle is also equipped with an aircraft-type sliding chute for emergency passenger evacuation.

F.2.2 Bogies

Each car body section is supported on four bogies which provide levitation, guidance, propulsion, and braking. Being a rigid frame manufactured with welded high-strength aluminum, the bogie supports the landing skids on which the vehicle rests when not levitated.

Each bogie carries eight levitation magnets. These magnets are 1,5 m long; they are placed in a horizontal position opposite the guideway - mounted linear induction stator and are connected to the bogie frame with a metalastic primary suspension (Figure F-4).

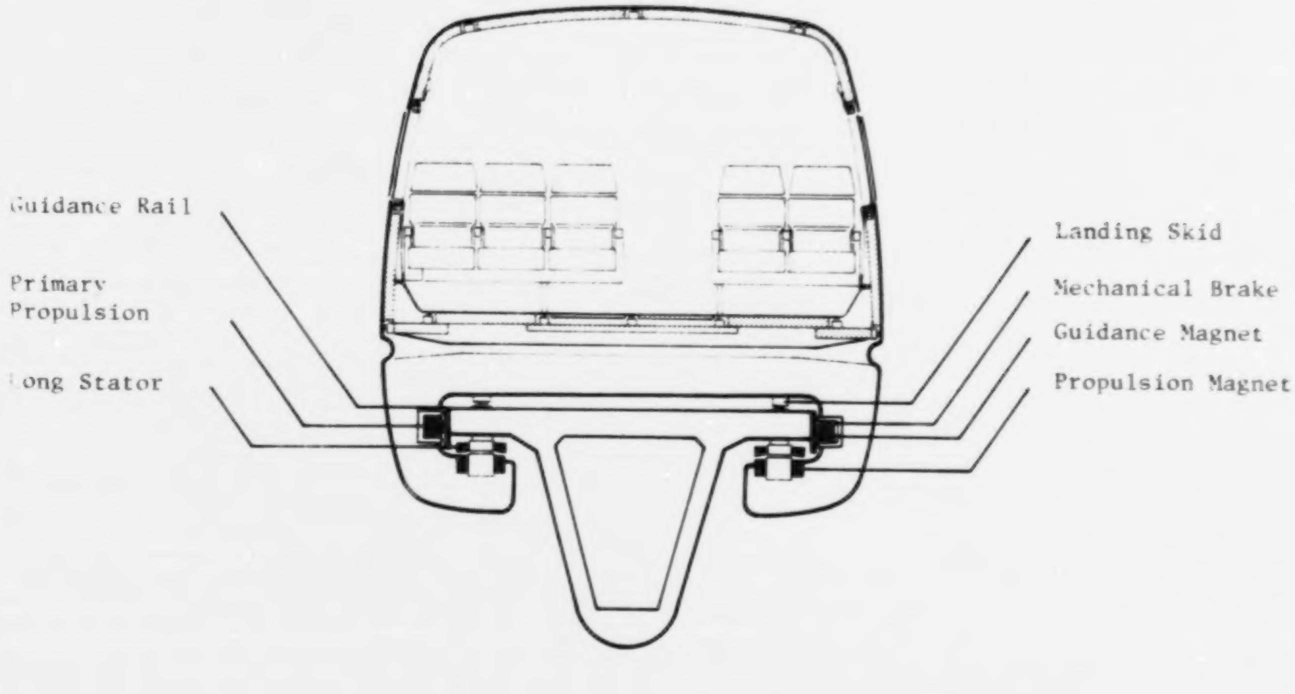
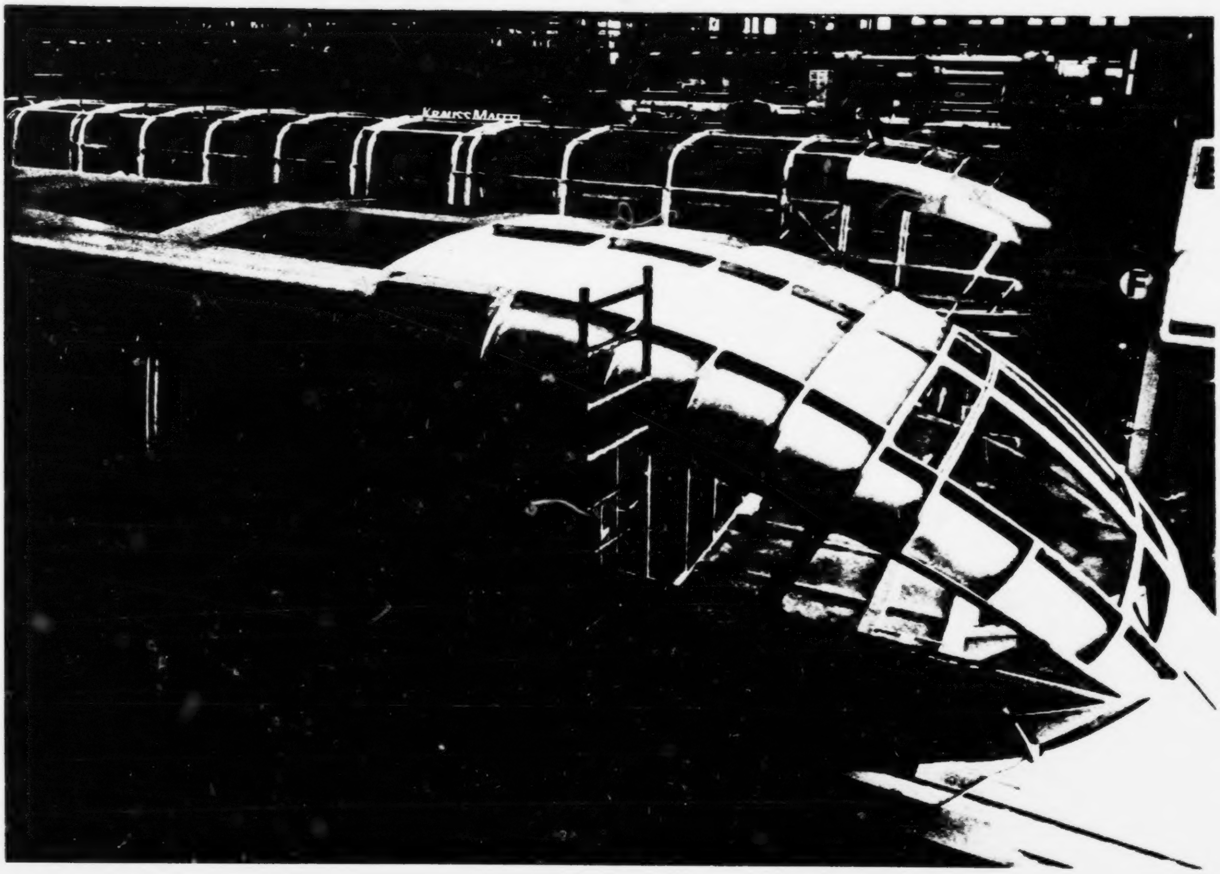

Guidance Rail
Primary Propulsion
Long Stator
Landing Skid
Mechanical Brake
Guidance Magnet
Propulsion Magnet

Figure F-2 Cross Section of the Maglev Vehicle



KRAUSS MAFFEI

Figure F-3 Car-Body Structure of Maglev Vehicle

Each bogie also carries six or eight guidance magnets; they are placed in a vertical position opposite the guideway-mounted guidance rails. The bogie is connected to the carbody through an air bag secondary suspension.

F.2.3 Propulsion

The vehicle is driven, without contact to the guideway, by a linear synchronous motor. The active part of that motor is an iron-cored long stator mounted under the guideway; the stator consists of a series of laminated steel plates to which is connected a three-phase cable winding; these are fixed to each side of the guideway.

Two static converters, located in each substation, feed a three-phase current, variable in frequency and voltage, into the stator windings. Thus a travelling field is generated with which the vehicle will move synchroneously. In order to limit the required voltage, the stator is subdivided into several feeder sections 400 m long; these are connected to the power supply consecutively.

As the traction power is transmitted inductively to the levitated vehicle, no power collectors are used.

Energy to actuate the levitation and guidance magnets is provided from four individual 440 V d.c. bus bars which also supply energy to the various equipments.

Up to 50 km/h, each bus bar is fed from a 4 4 Ah buffer battery. At higher speeds, each bus bar is supplied by 64 linear generators that tune out the energy, free of contact to the track, by utilizing the flux modulation of the exciting magnets.

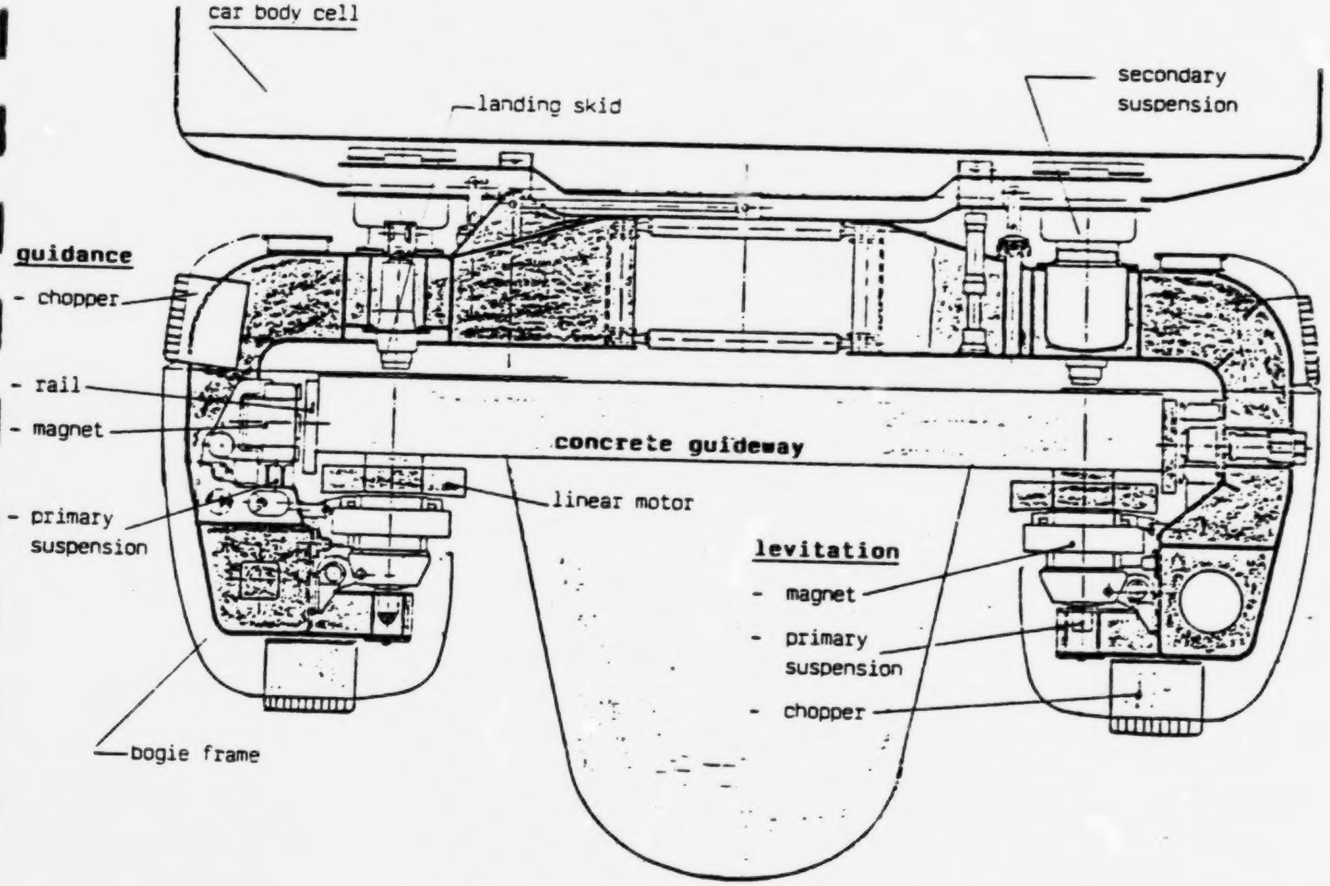

car body cell
landing skid
secondary suspension
guidance
- chopper
- rail
- magnet
- primary suspension
concrete guideway
linear motor
levitation
- magnet
- primary suspension
- chopper
bogie frame

Figure F-4 Cross-Section of the Maglev Bogie

F.2.4 Braking

Emergency braking is obtained by deactivating the levitation magnets: the skids drop on the guideway-mounted skid pads.

Dynamic Service braking at 0,8 m/s^2 is obtained by reversing the polarity of the electrical field.

Parking braking is obtained by using hydraulic friction brakes; they can also be used as service brakes in the event of a malfunction of the dynamic brakes.

F.2.5 Vehicle Performance

Acceleration and braking performance of the Maglev vehicle are shown in Figure F-5, which is the basis for Figure F-1.

F.3 Infrastructure

This section of Appendix F corresponds to Section 6.5 of Chapter 6 and provides complementary documentation on it. Sections 6.5 and F.3 are arranged in the same order.

F.3.1 Guideway Layout

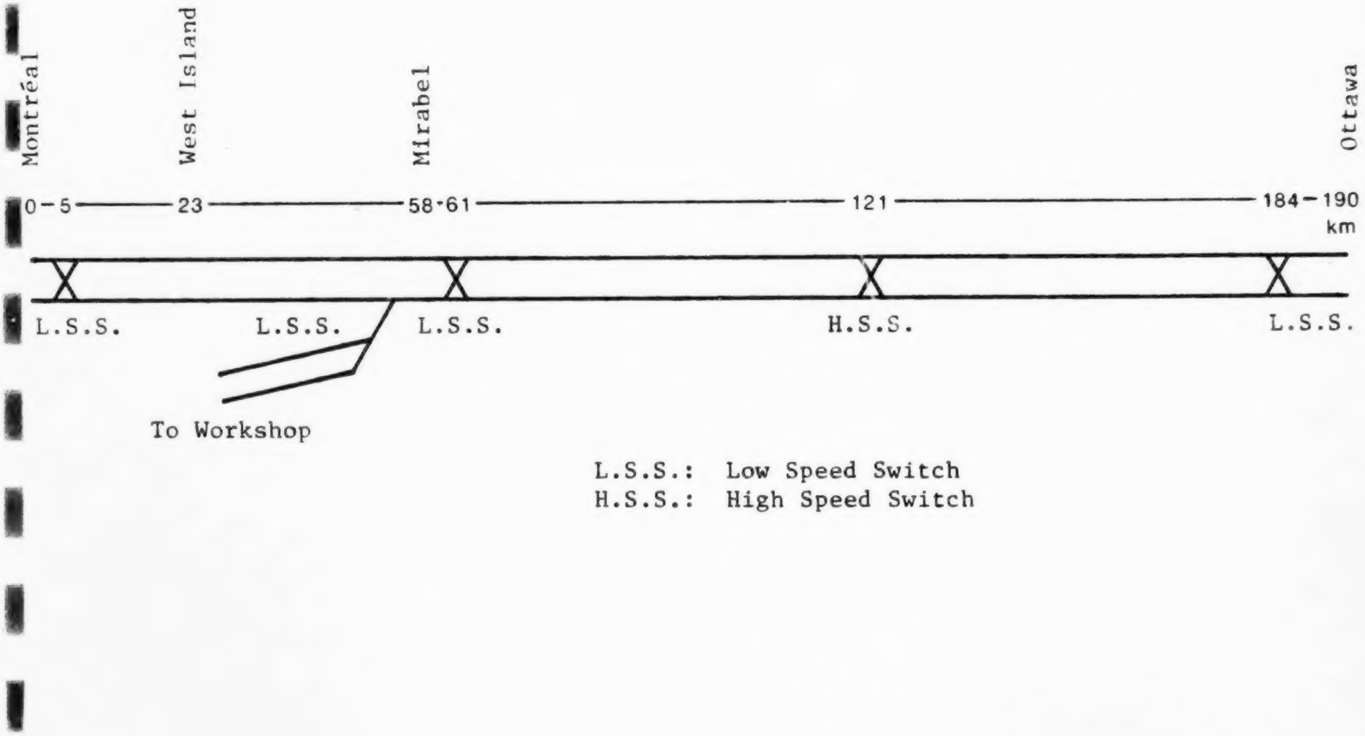
The guideway layout adopted for the Maglev System definition is shown schematically in Figure F-6. Its principal features are described below and reasons for their adoption are discussed.

The choice of a double guideway is related to the conditions under which a Maglev system would effectively be built between Montreal and Ottawa. If such a project was undertaken, the system would surely extend beyond the Montreal-Ottawa link: minimally to Toronto through Kingston and, in all likelihood, also West of Toronto towards Windsor and East of Montreal to Quebec City.

For such a system, a double guideway would inevitably be needed between Montreal and Toronto. The difficulties associated with building that double guideway must be faced already when building what is presumed to be the first leg of the route, the Montreal - Ottawa system envisioned in the present study.

When that system will be optimized later in the study, the system definition may be changed to a single guideway, as a double guideway is not effectively needed to serve the Montreal-Ottawa traffic.

The Maglev route starts in Windsor Station with two (single) guideways and three platforms, a clearance of 8,5 m being provided between the bottom of guideway beams and the top of rail; the skid plane for the vehicle will then be 9,3 m above top of rail. The actual location of the platforms is discussed in greater detail in Section F.7.



Montréal
West Island
Mirabel
Ottawa
0-5
23
58-61
121
184-190
km
L.S.S.
L.S.S.
L.S.S.
H.S.S.
L.S.S.
To Workshop

L.S.S.: Low Speed Switch
H.S.S.: High Speed Switch

Figure F-6 Summary Guideway Schematic for Maglev

The route starts at kilometric point 0+0, located 150 m beyond the end of these platforms.

Approximately 2 km from the Montreal Maglev Terminal at Windsor Station, a first double crossover will be located to allow Maglev trains coming from any guideway lane into (or out of) the terminal to move to the other lane. In the interest of reducing costs, this double crossover will effectively be built as a succession of two single crossovers, each made of two low-speed switches. The sequence of four switches, together with the length required for widening the space between both guideways, occupies a length of 1,6 km approximately. Fortunately, around km 5, the route is straight, and there is sufficient space available, as there is no other feature along the guideway.

The Maglev guideway remains over the CP right-of-way until km 17+500; from that point until km 21 approximately, the guideway is built on private property; for some distance it is almost at the western edge of Dorval Airport. Along this stretch, the guideway is built slightly below grade to clear the landing paths of the airport; there is no other feature of interest to operations. From km 21 to 23 approximately, the guideway is again built over a railway, this time, the CN Doney Spur.

From km 22 to km 42, the guideway is built on a new right-of-way acquired from private owners; clearance between the underside of the guideway beam and the terrain is normally 5 m. Two rivers are crossed: Rivière des Prairies and Rivière des Mille-Iles; the crossing lengths are 700 m and 600 m, respectively, based on their location and the angle between the route and the river. These are the only guideway features in that area.

From km 42 to km 67 approximately, the guideway is routed on federal land: Mirabel Airport. Entering this zone, the guideway is still elevated so that there is a 5 m clearance between the underside of the guideway and the streets, roads, and highways over which it passes.

Around km 52, however, the guideway starts descending as Mirabel Airport Station, met at km 57+800, is in the basement of the Terminal building.

Beyond the station, the guideway ascends back to its normal elevation, so as to provide sufficient clearance for a major road crossed at km 64+600. A second double crossover is found between km 62 and km 64; as trains will travel at reduced speed near the station, it will be built with low speed turnouts.

After leaving federal property around km 67, the guideway is routed through an agricultural area, crossing Rivière du Nord (100 m) at km 85+700, and reaching Ottawa River at km 101. The river crossing is 1 100 m long, so that Ontario is reached at km 102+100.

Then is no significant guideway feature until km 120, where another double crossover will be found, near Caledonia Springs. As there are no speed restrictions in this area, the crossover will be made with four successive high speed turnouts arranged as two single cross overs.

There is no significant feature on the layout until km 181+500, where the guideway joins CP Subdivision M.&O. and is built alongside the existing track.

Upon joining the railway, the Maglev guideway starts descending so as to pass under Highway 417, the existing structures probably having to be rebuilt. Ottawa Station will be reached at grade at km 189+500.

For ease of construction and maintenance, the double crossover required near the terminal will be located around km 184. As it is in reduced speed territory, it will be built with four low speed turnouts.

F.3.2 Right-of-Way Requirements

Given the procedures outlined in Sub-section 6.5.2 for acquiring land or air rights for a Maglev guideway, what are effectively the space requirements? In other words, how is Table 6-2 derived?

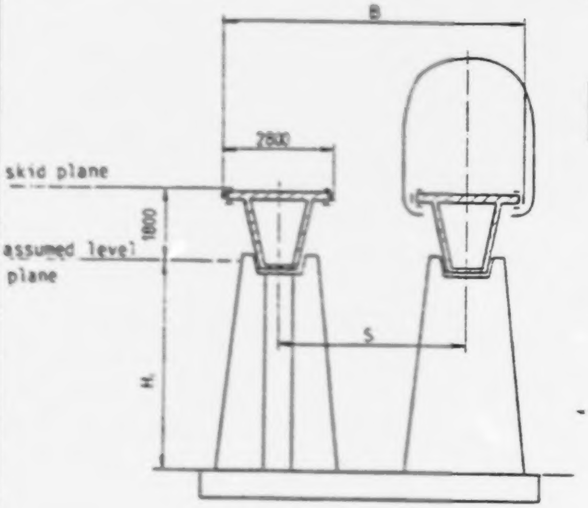
In urban areas, the guideway will be built over railways or on new rights-of-way; it will be elevated in any case and the speed will be restricted to 200 km/h.

Over a railway, as seen in Figure F-13 and F-14 the supporting structure would consist of a rigid frame providing enough width for 2 or 3 tracks und er the the double guideway. Based on the width of the columns of that structure and considering the necessary clearances, a right-of-way of 15 m wide should suffice.

In the case of a new right-of-way, the same width should suffice, as the guideway will normally be accessible from neighboring streets without difficulty for emergency evacuation. This applies to Montreal Island and to Ottawa. The guideway envelope for an elevated guideway is illustrated in Figure F-7, which shows that the space occupied is 7,0 m wide at 200 km/h.

In suburban areas, which implies mainly Laval, Deux-Montagnes, Boisbriand, and Blainville, the speed limitation is lifted, due to the much lower density of development. According to Figure F-7, the right-of-way requirement would widen to 7,9 m at 400 km/h, a speed that is not yet reached. Based on easy accessibility, the same right-of-way width should be satisfactory in this territory. But a right-of-way of 15 m should be sufficient for an elevated guideway.

In rural areas, a speed of 400 km/h can be reached and the road network a much less dense, making emergency access to the guideway difficult. Due to the insufficient number of roads, an access road will


B
2800
skid plane
1800
assumed level plane
S
H

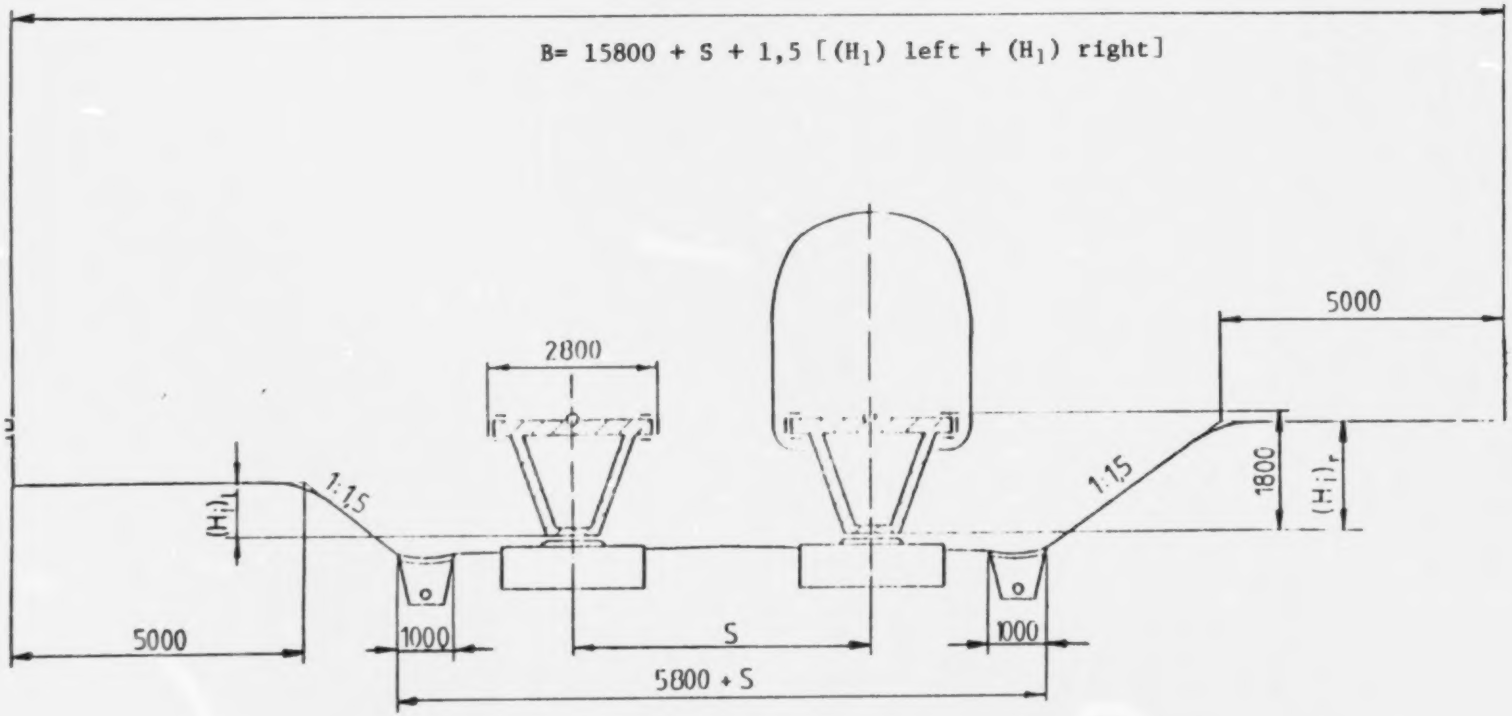
	v [km/h]		
	200	300	400
B [m]	7,00	7,20	7.90
s [m]	4,20	4,40	5,10

Figure F-7 Clearance for an Elevated Guideway have to be built during guideway construction. This road should be built to standards allowing its future use by road vehicles and kept open as an emergency access road once the system is in operation. For these reasons, a wider right-of-way should be acquired: 30 m. The low price of rural land between Montreal and Ottawa favors this approach, which also prevents exceeding the limits of a too narrow right-of-way during construction.

Near Mirabel Airport and near Ottawa, the guideway will be built at grade. As seen in Figure F-8, the total width required for the guideway is 20,0 m at 200 km/h and 20,9 m at 400 km/h, if the guideway is truly at grade. The width would be greater if the guideway is in a cut aron fill. A right-a-way width of 30 m would be sufficient to house the guideway and the emergency access road white maintaining the necessary clearances.

The requirements resulting from the above considerations are displayed in Table F-5.

	v [km/h]		
	200	300	400
s [m]	4,20	4,40	5,10



B= 15800 + S + 1,5 [(H$_1$) left + (H$_1$) right]
5000
2800
1:1,5
(H$_1$)$_l$
1:1,5
1800
(H$_1$)$_r$
5000
1000
S
1000
5800 + S

Figure F-8 Right-of-Way Requirement for a Guideway At Grade

Table F-5

Access Road Requirements along the Maglev Route

Map	Start	Finish	Length of Access Road
C-2	0 000	14 000	0
C-3	14 000	32 000	9 (23-32)
C-4	32 000	52 000	20
C-5	52 000	72 000	19 (tunnel)
C-6	72 000	92 000	20
C-7	92 000	112 000	20
C-8	112 000	132 000	20
C-9	132 000	152 000	20
C-10	152 000	172 000	20
C-11	174 000	189 500	9

F.4 Design and Cost of Guideway Foundation Elements

There are four guideway structural elements; these are, from the top down:

- a beam, which supports the vehicle and the fixed propulsion, guidance, and control equipments;
- a bearing to allow the necessary adjustment between the beam and its support element; this bearing will allow the maintenance of the necessary positional tolerances on the beam in the case of displacements of the support elements following soil movements or ground subsidence.
- a column or pier, to develop the necessary clearance between the underside of the beam and the terrain; this element is inexistent when the guideway is built at grade;
- a foundation element to transmit to the ground the live and dead loads corresponding to the vehicle, the weight of the beam and its equipments, and that of the pier or column, when there is one;

Designs for the foundation elements will now be described individually; the proposed design and the estimated construction cost will be given for each. As the proposed design results from assumed design conditions, these will first be described.

F.4.1 Design Conditions and Parameters

Design conditions and parameters for the Maglev guideway consist of loads and displacements. Static loads on foundation elements consist chiefly of the weight of the guideway beams and their equipments. Dynamic loads are related to the vehicle and its propulsion and braking. Allowable displacements are related to the very stringent tolerances required for the efficient operation of the magnetic levitation and propulsion functions.

Based on the design of the vehicle, the static load is estimated at 25 kN/m for the standard span of 25 m.

Vertical dynamic loads associated with the acceleration and braking of the vehicle, given its performance, are estimated at 45 kN/m. Contrary to a typical railway vehicle which produces concentrated loads at axles (this is why maximum axle load is such an important design parameter), the Maglev vehicle indeed produces a load that can be considered as uniformly distributed.

Horizontal dynamic loads associated with braking, acting longitudinally along the guideway, can also be considered as uniformly distributed along the span and are estimated at 14 kN/m.

The maximum lateral load, including the effect of wind and that of the centrifugal force, is estimated at 16 kN/m.

The worst loading case is the combination of the minimum vertical load and the maximum lateral load.

Maximum allowable displacements, measured at guideway beam bearings, differ depending on whether permanent or temporary deformations are being considered.

For a 24 m span, the maximum allowable permanent deformations are the following:

- vertically, as resulting from static loads or foundation settlement:
  - 6 mm if there is periodicity in the deformations, from one beam support to the next,
  - 7,5 mm if there is no periodicity in the deformations;
- laterally, as resulting from centrifugal forces:
  - 4 mm if there is periodicity,
  - 5 mm if there is none.

If these maximum values are exceeded, or reached, readjustment of the alignment or profile is necessary.

Similarly, for a 24 m span, the maximum values for temporary deformations are the following:

- longitudinally, as a result of dynamic braking loads:
  a maximum displacement of 7 mm under the maximum braking force of 700 kN;
- laterally, as a result of centrifugal forces:
  a maximum displacement of the column (or pier) head of 1 mm resulting from the application of a lateral force of 4 kN/m over half of each of two successive standard beams of 25 m in length;
- upon the application of no more than 5% of the maximum braking force, the surface on which the beams are supported must not rotate more than 0,005 radian around the column (or pier) axis.

Design principles are those of the American Association of State Highway and Transportation Officials (AASHTO), in their Standard Specification for Highway Bridges.

F.4.2 Foundation Elements: Guideway at Grade

The choice of a foundation for the guideway depends on three factors: the height at which the guideway is built, whether the guideway is curved or straight, and the quality of the soil. Designs and costs will be given for each case.

The most simple case is of course a straight guideway built at grade on good soil: rock or till. In such a case, the foundation is only subject to vertical loads and horizontal loads due to braking forces; it consists essentially of a concrete pad resting on a stone mat or an insulated pad to prevent freezing of the ground under the foundation and the resulting ground heave. The concrete footing is 2 000 mm long along the axis of the route, 2 800 mm wide across it, and 500 mm thick. The footing requires 2,8 m^3 of concrete of B25 quality, and 200 kg of St 420/500 reinforcing steel at the following unit prices (in place): $150/$m^3$, $0,75/kg. Adding $180 for a stone mat or insulation, the total cost is $750/footing.

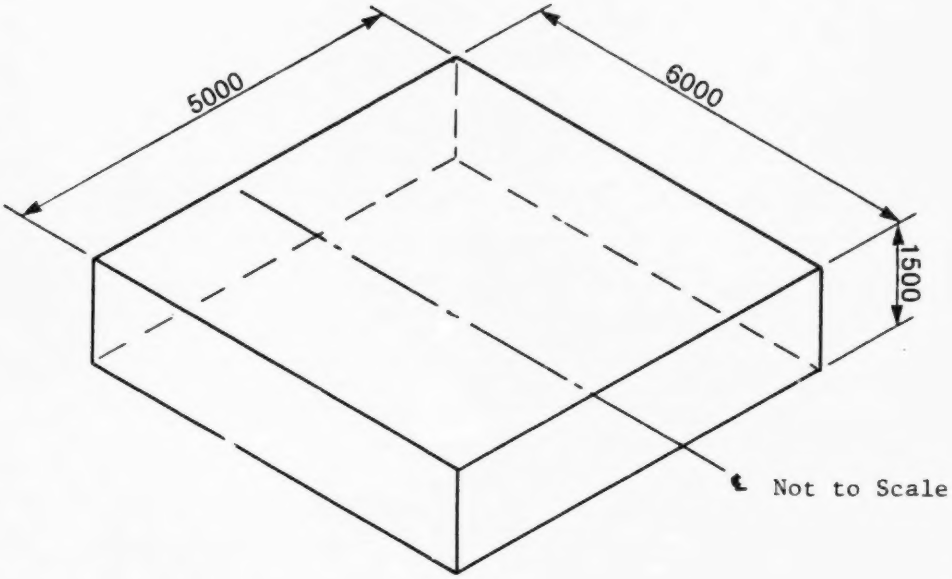
The above footing is sufficiently heavy to resist to centrifugal forces in curves. Hence, the design for a straight guideway is also applicable to a curved guideway.

If the guideway is built at grade on poor soil such as sand or clay, the same footing can be used, but 4 piles will be needed to generate the necessary bearing capacity through friction or by resting on bedrock. Each pile will have a resistance of 500 kN and be 20 m long (or less if bedrock is found closer to the ground). At $75/m, the piles will cost a maximum $6 000 plus a set-up cost of $1 000 for the pile contractor. The total cost of the foundation element, whether on a tangent or in a curve, becomes $3 100 (for a single guideway) if bedrock is at 5 m below ground. The cost increases by $300 for each additional meter in the depth of bedrock up to a maximum of $7 600 if bedrock is at 20 m below ground.

F.4.3 Foundation Elements: Elevated Guideway

The next series of cases is for a typical elevated guideway, when a clearance is provided between the underside of the guideway beam and the terrain. The following discussion presumes the guideway beam rests on a A-shaped pier, not on a cruciform column.

When the guideway is elevated, the foundation must bear, in additi
to vertical static and dynamic loads transmitted by the pier, excentric longitudinal loads, because the clearance introduces some distance between the foundation element and the point of application



Item	Dimensions	Quantity	Unit Cost	Item Cost
B25 Concrete	6000 x 5000 x 1500	45,0 m^3	\$150,00/m^3	\$ 6 750
ST420/500 Steel	60 kg/m^3	2700,0 kg	\$ 0,75/kg	\$ 2 025
Insulation	3" thick	-	Global	\$ 725
			TOTAL	\$ 9 500

Notes

1. Design for single guideway with 25 m beams
2. Design applicable to tangent alignment only
3. Cost of Pier or Column not included
4. This footing must rest on rock or till
5. All dimensions in mm unless ortherwise specified
6. All costs in CDN$ 1983

Figure F-9 Footing for a Straight Guideway with a 5 m Clearance of the braking force; is excentricity, and the induced moment, increase with the clearance. Naturally, if the elevated guideway is curved, there are also lateral loads due to the centrifugal forces.

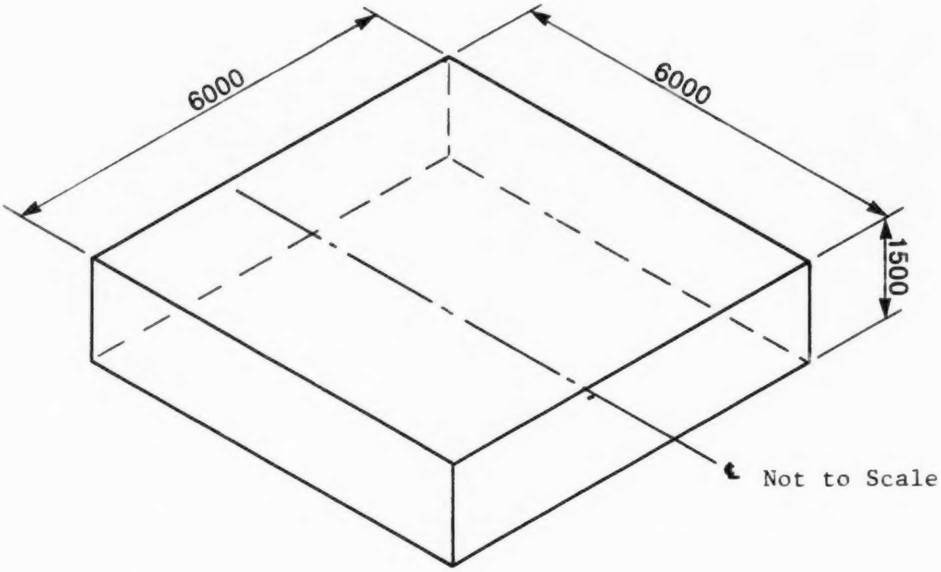
Thus, for an elevated guideway, designs for footings and pile caps will increase in sturdiness in proportion to the clearance, forcing costs up progressively. Different designs will have to be used for straight and curved guideways. Designs and costs were analyzed for clearances of 2, 5, and 7 m. This was done separately depending on soil conditions.

F.4.4 Footings for Elevated Guideways on Good Soil

The starting point is naturally a straight guideway with a clearance of 2 m, built on rock or till. For a single guideway with 25 m beams, the footing uses 25,3 m^3 of B25 concrete and 1 520 kg of St 420/500 steel for a cost of $5 540 per footing.

For a curved guideway, the footing must be somewhat larger, so that its weight prevents it from moving under lateral loads; the cost is $ 6 700, approximately 20% more than for a straight guideway.

Footings for a clearance of 5 m are shown in Figures F-9 (straight) and F-10 (curved). A footing for a curved guideway with a 7 m clearance, based on similar analyses, would cost $16 200. Based on the same ratio as in the case of a 5 m clearance, the footing for a straight guideway with a 7 m clearance would cost 83% of that, or $13 400.



Item	Dimensions	Quantity	Unit Cost	Item Cost
B25 Concrete	6000 x 6000 x 1500	45,0 m^3	\$150,00/m^3	\$ 6 750
ST420/500 Steel	60 kg/m^3	2700,0 kg	\$ 0,75/kg	\$ 2 025
Insulation	3" thick		Global	\$ 725
			TOTAL	\$11 500

Notes

1. Design for single guideway with 25 m beams
2. Design applicable to curved alignment
3. Cost of Pier or Column not included
4. This footing most rest on rock or till
5. All dimensions in mm unless otherwise specified
6. All costs in CDN$ 1983

Figure F-10 Footing for a Curved Guideway with a 5 m Clearance

F.4.5 Pile Caps for Elevated Guideways on Poor Soil

When the guideway is built on sand or clay, piles will be used to generate the bearing capacity required to provide sufficient resistance to bear the loads while respecting maximum displacements. In principle, the piles will generate that bearing capacity through friction and their necessary length will be calculated accordingly. If bedrock is closer than the calculated pile length, piles will be driven just long enough to transmit the loads to bedrock. For bedrock at less than 5 m below ground, piles will not be driven: it will then be cheaper to compact the sand or clay or replace it with a more suitable material, on which a footing will be built.

The starting point for foundation elements for bad soils is a straight guideway with a 2 m clearance. The design consists of a 4 000 x 4 000 x 1 000 mm pile cap resting on four piles. The fixed cost amounts to \$4 200 and corresponds to 16 m^3 of B25 concrete, 1 000 kg of St 420/500 reinforcing steel and the set-up cost for pile driving. The variable cost ranges between a minimum of \$1 500 if bedrock is found after driving the piles 5 m, to a maximum of \$9 600 if the piles must be driven for the full length of 32 m to generate a resistance of 800 kN through sheer friction. The total cost ranges from \$6 700 to \$13 800 with bedrock depth.

The same pile cap design will be used for a curved guideway. The only difference is that piles must generate 1 000 kN each and that the maximum pile length is 40 m rather than 32 m. At this point, the total cost reaches up to \$16 200.

If the clearance is 5 m, the same pile cap dimensions can be used, but six piles are needed instead of four; their maximum length is also 32 m. For a single guideway with 25 m beams, the cost of a pile cap will vary from \$6 400 (at 5 m) to \$18 600 (at 32 m) depending on pile length. In the case of a curved guideway the maximum cost (at 40 m) will be \$22 200.

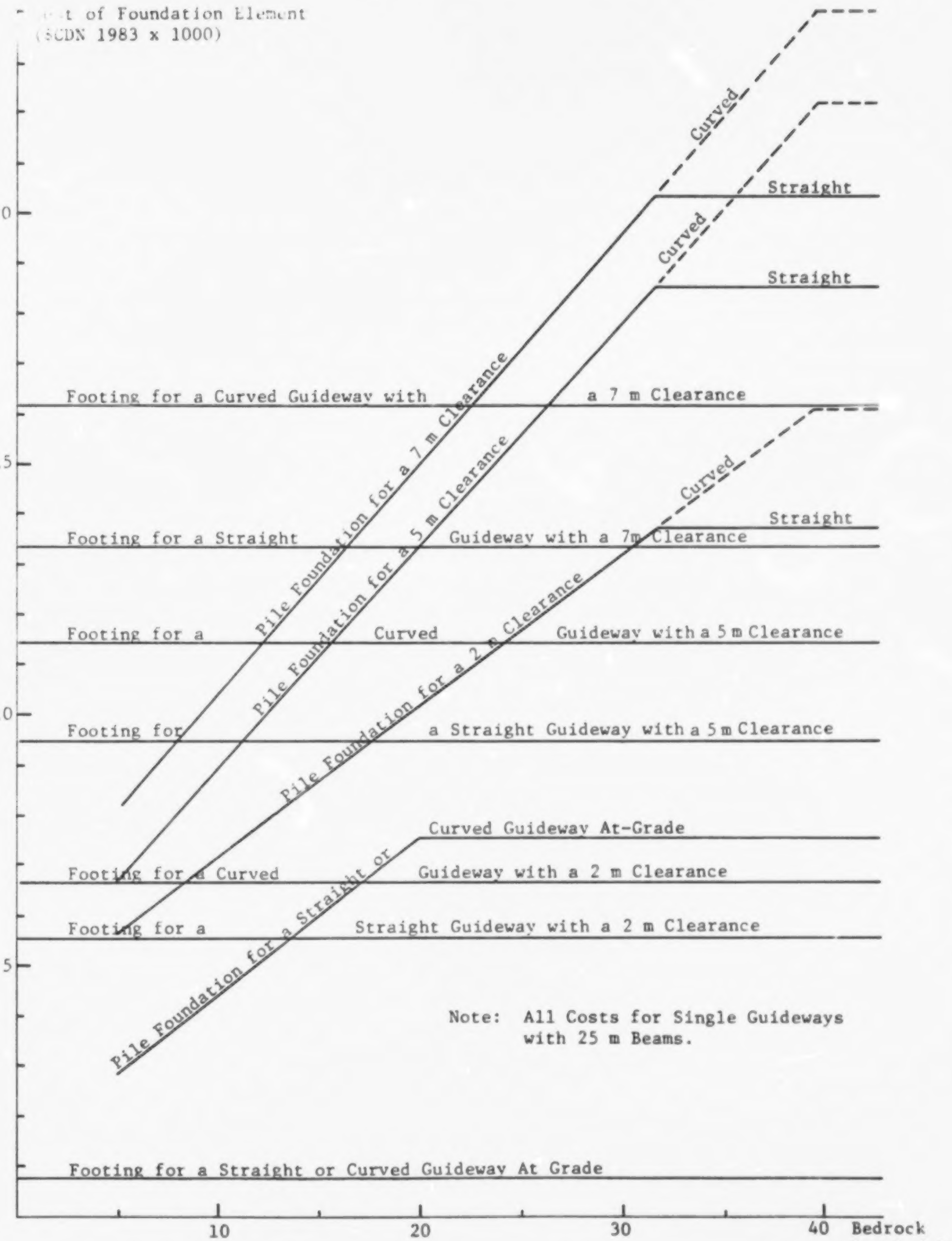


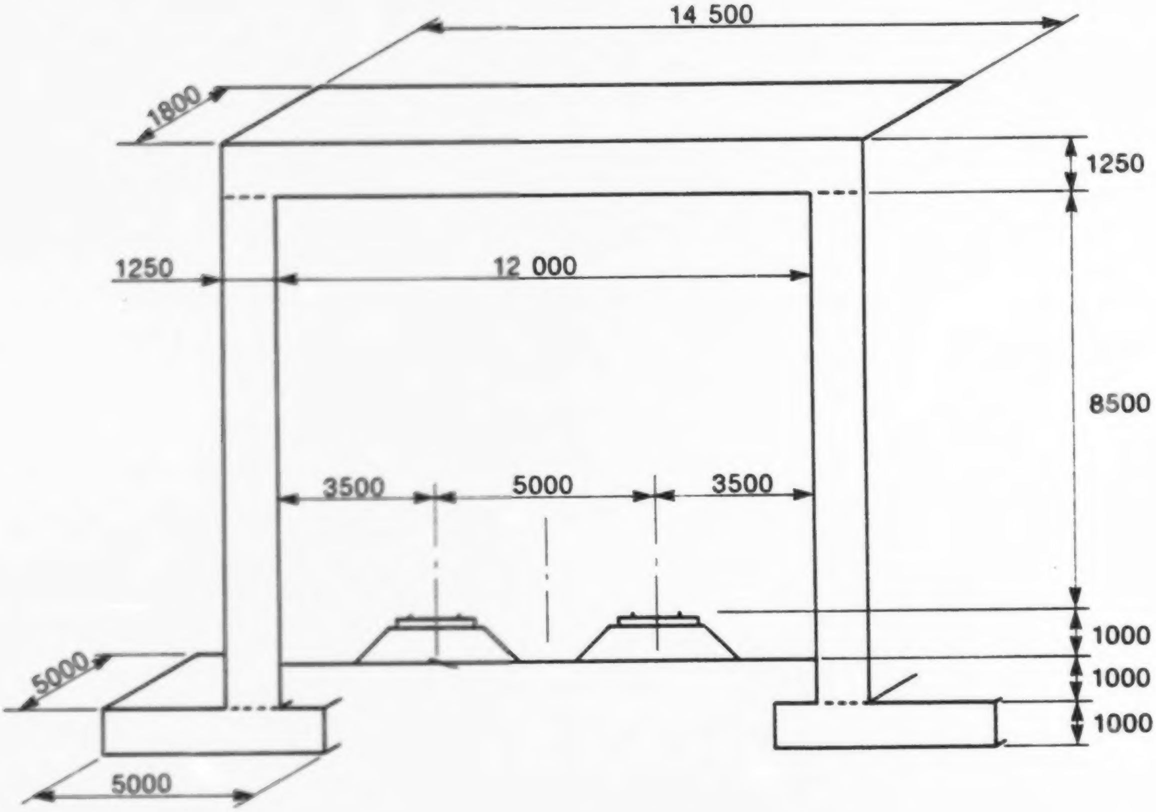
Figure F-11 Cost Behavior of Guideway Foundation Elements

For a greater clearance of 7 m, which implies a sturdier pier, a larger pile cap is needed, with dimensions of 5 000 x 5 000 x 1 000; but six piles will suffice. For a straight single guideway with 25 m beams, the cost per pile cap will vary from $8 250 (bedrock at 5 m) to $20 400 (pile length of 32 m). For a curved guideway, the cost per foundation element will be the same to a bedrock depth of 32 m, but the maximum cost will be $24 000 at a bedrock depth of 40 m.

The variation of the cost of foundation elements with soil type, guideway clearance, and guideway alignment are shown in Figure F-11, which summarizes the above discussion.

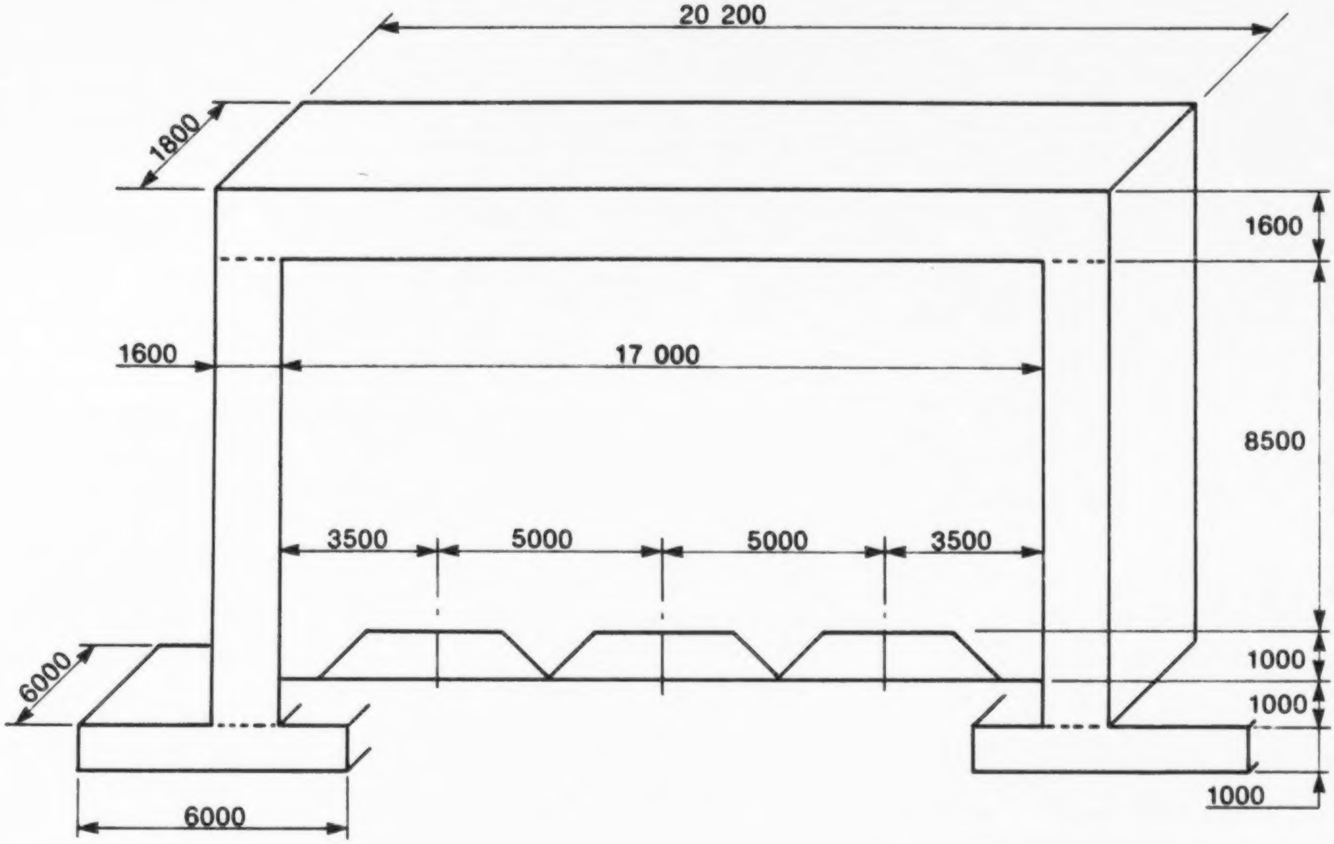
F.4.6 Rigid Frames for Elevated Guideways over Railways

These frames were discussed at the end of Sub-section 6.6.6. Figure F-12 shows the structural concept dimensions, materials quantities and costs for a frame over 2 tracks. Figure F-13 shows the same for a frame over 3 tracks.


14 500
1800
1250
1250
12 000
8500
3500
5000
3500
1000
1000
1000
5000
5000

ITEM	DIMENSIONS	QUANTITY	UNIT COST	ITEM COST
Footings				
B25 Concrete	2(5000x5000x1000)	50,0 m³	\$150/m³	\$ 7 500
ST III Steel	60 kg/m³	3000 kg	\$0,75/kg	\$ 2 250
Columns				
B35 Concrete	2(1250x1800x10500)	47,2 m³	\$260/m³	\$ 12 300
ST III Steel	90 kg/m³	4250 kg	\$0,75/kg	\$ 3 200
Beam				
B35 Concrete	(14500x1800x1250)	32,6 m³	\$260/m³	\$ 8 500
ST III Steel	90 kg/m³	2934 kg	\$0,75/kg	\$ 2 200
Insulation	2(5000x5000)	50,0 m²	\$ 30/m²	\$ 1 500
			TOTAL	\$ 37 450

Figure F-12 Rigid Frame over 2 Tracks


20 200
1800
1600
1600
17 000
8500
3500
5000
5000
3500
1000
1000
6000
1000
6000

ITEM	DIMENSION	QUANTITY	UNIT COST	ITEM COST
Footings				
B25 Concrete	2(6000x6000x1000)	72,0 m^3	\$150/m^3	\$ 10 800
ST III Steel	60 kg/m^3		\$0,75/kg	\$ 3 250
Columns				
B35 Concrete	2(10500x1600x1800)	60,5 m^3	\$260/m^3	\$ 15 700
ST III Steel	90 kg/m^3	2720 kg	\$0,75/kg	\$ 2 050
Beam				
B35 Concrete	(20200x1800x1600)	58,2 m^3	\$260/m^3	\$ 15 100
ST III Steel	90 kg/m^3	5240 kg	\$0,75/kg	\$ 3 900
Insulation	2(6000x6000)	72,0 m^2	\$ 30/m^2	\$ 2 150
			TOTAL	\$ 52 950

Figure F-13 Rigid Frame over 3 Tracks

F.5 Guideway Configuration Design

All guideway foundation elements were described in the preceding section. The frequency with each type will be used depends on the following factors:

- whether the guideway is at grade or elevated,
- if the guideway is elevated, what clearance between the terrain and the underside of the beam;
- the nature of the sub-soil, which determines whether piles are necessary;
- when piles are necessary, whether their full resistance will be developed through friction alone or whether they will only transmit the loads to a shallow bedrock;
- whether the guideway is routed over a railway right-of-way in which case a rigid frame such as shown in Figures F-11 and F-12 would be used.

All the above naturally applies to a "typical" guideway whose configuration would be determined solely by topographical and geological features of the route. If local features, such as river or railway crossings, are found, the "typical" guideway would be modified. Such cases would require the use of "special" structures whereas only the "typical" guideway structure is discussed be below.

Sub-soil conditions along the Maglev route are shown an Figure F-14, which was made up with the Maglev route maps given in Appendix C and sub-soil information from published geological maps and soundings in the area, with complementary information from the Alternatives to Air Study.

Based on geological data along the Maglev route, a detailed inventory of foundation types along the route was performed. The results are summarized in Table F-6.

Table F-6

Guideway Foundation Elements by Type
(Page 1 of 2)

Guideway Clearance (m)	Foundation Type					
	Footing			Piles		
	Sub-Soil Type	Straight Guideway	Curved Guideway	Pile Length(m)	Straight Guideway	Curved Guideway
0 m	Rock or Till	5,3 km $ 2,06 M	0,4 km $ 2,06 M	10	0,2 km $ 2,37 M	-
	Sand or Clay (5m)	0,7 km $ 2,08 M	-	15	0,6 km $ 2,49 M	-
			-	40	1,7 km $ 2,61 M	-
2 m	Rock or Till	1,0 km $ 2,72 M	-	10	0,6 km $ 2,85 M	-
	Sand or Clay (5m)	-	3,0 km $ 2,97 M	15	0,3 km $ 2,97 M	-
				40	1,5 km $ 3,38 M	-
5 m	Rock or Till	42,9 km $ 3,20 M	2,3 km $ 3,36 M	10	4,5 km $ 3,14 M	1,0 km $ 3,14 M
	Sand or Clay (2m)	0,5 km $ 3,31 M	-	15	3,2 km $ 3,32 M	-
				20	7,8 km $ 3,50 M	-
	Sand or Clay (5m)	15,7 km $ 3,43 km	2,2 km $ 3,64 km	25	15,4 km $ 3,68 M	-
				30	4,3 km $ 3,86 M	-
				40	52,5 km $ 3,93 M	-
8,5 m (2 tracks)	Rock or Till	7,1 km $ 3,50 M	1,8 km $ 3,50 M	10	3,1 km $ 3,80 M	0,6 km $ 3,80 M
	Sand or Clay (2m)	0,3 km $ 3,56 M	-	15	-	1,2 km $ 3,98 M
	Sand or Clay (5m)	0,3 km $ 3,62 M	-	20	1,8 km $ 4,16 M	-

Table F-6

Guideway Foundation Elements by Type
(Page 2 of 2)

Guideway Clearance (m)	Foundation Type					
	Footing			Piles		
	Sub-Soil Type	Straight Guideway	Curved Guideway	Pile Length(m)	Straight Guideway	Curved Guideway
8,5 m (3 tracks)	-	-	-	15	0,9 km $ 4,26 M	-
				25	3,2 km $ 4,62 M	-
				30	1,6 km $ 4,80 M	-
TOTAL	-	73,8 km	9,7 km	-	103,2 km	2,8 km

F.6 Cost of River Crossings

The steps of the method used for estimating the cost of river crossings are the following. First, the "base" cost of the structure is established from its length (Column 2 of Table F-7), its clearance and foundation type (Columns 3 and 4, based on Table F-6), and its kilometric cost (from Table F-8); the base cost for the crossing is given in Column 5 and corresponds to the (unapplicable) assumption that the river could be crossed with 25 m beams at the given clearance.

Then, in each case, the index of cost changes, for the assumed conditions (Columns 2 and 3 of Table F-7) and the required structures (as given in Table F-9) is found in Table F-10. Whenever an index does not exist in Table F-10 (such as for a 20 m clearance with a 72 m beam), the next higher index in the same column is used (211 for a 25 m clearance in this case).

To establish the cost surplus is then only a matter of multiplying the base cost (Column 6 in Table F-7) by the index (divided by 100 and reduced by 1 to avoid double counting). In total then, river crossings result in a construction cost surplus of $6,31 M for the guideway structure. Approaches to these crossings would add, say, 30% to these costs, bringing them up to $8,20 M.

Finally, the guideway structures will have to be raised to 8,5 m above all railway crossings. There are ten such crossings, at km 25, 42, 67, 73, 100, 104, 108, 118, 140. In each case, the guideway which has a normal clearance of 5 m at these locations, will have to be raised 3,5 m to cross the track. For an approximation of the corresponding cost surplus, one can presume that the guideway has a sloping profile of 1% on each side of the crossing, for 350 m. Then a total of 7 km of guideway will be sloped (350 m x 2 sides x 10 crossings) and cost 15% more (compared to numbers given in Table F-8). Based on the average guideway cost of $3,52M/km, the corresponding cost surplus may be estimated at $3,67M (7 km x $3,52M/km x 15%).

Table F-7

Cost Surplus for River Crossings

River Crossing	Foundation Type	Assumed Clearance (m)		Maglev Crossing Length (m)	Base Cost ($M)	Cost Index	Cost Surplus ($M)
		Base	Adjusted				
des Prairies A	Piles (5 m)	5	15	216	$ 0,64	211	$ 0,71
des Prairies B	Footings	5	15	144	$ 0,46	211	$ 0,51
des Mille-Iles A	Piles (5 m)	5	12	216	$ 0,64	211	$ 0,71
des Mille-Iles B	Piles (5 m)	5	12	144	$ 0,43	211	$ 0,48
du Nord	Piles (30 m)	5	15	72	$ 0,28	211	$ 0,31
Ottawa	Footings on 2 m clay	5	27	720	$ 2,38	229	$ 3,07
		5	12	72	$ 0,24	173	$ 0,27
South Nation	Piles (20 m)	5	8	72	$ 0,25	211	$ 0,17
Cobbs Lake Creek	Piles (40 m)	5	8	36	$ 0,14	163	$ 0,09
TOTAL							$ 6,31

Table F-8

Unit Kilometric Costs for Guideway Construction
($CDN, 1983)

Guideway Clearance	Sub-Soil Type			
	Rock or Till		Sand or Clay	
	Tangent	Curve	Tangent	Curve
0 m (At Grade)	$ 2,14 M	$ 2,14 M	$ 2,33 M Minimum	$ 2,33 M Minimum
			$ 2,56 M Maximum	$ 2,56 M Maximum
2 m (above terrain)	$ 2,80 M	$ 2,80 M	$ 2,81 M Minimum	$ 2,81 M Minimum
			$ 3,46 M Maximum	$ 3,46 M Maximum
5 m (above terrain)	$ 3,28 M	$ 3,44 M	$ 3,04 M Minimum	$ 3,04 M Minimum
			$ 4,01 M Maximum	$ 4,30 M Maximum
7 m (above terrain)	$ 3,72 M	$ 3,94 M	$ 3,30 M Minimum	$ 3,30 M Minimum
			$ 4,27 M Maximum	$ 4,27 M Maximum
8,5 m (above 2 tracks)	$ 3,58 M	$ 3,58 M	$ 3,70 M Minimum	$ 3,70 M Minimum
			$ 4,96 M Maximum	$ 4,96 M Maximum
8,5 m (above 3 tracks)	$ 4,20 M	$ 4,20 M	$ 4,29 M Minimum	$ 4,29 M Minimum
			$ 5,55 M Maximum	$ 5,55 M Maximum

Note: These costs are applicable to a double guideway built entirely with 25 m beams.

Table F-9

Structural Requirements of River Crossings

River	Crossing Length (m)	Rail Spans (m)	Maglev Spans (m)	Clearance Required (m)
Rivière-des-Prairies A (km 26) B	200 120	2 x 100 1 x 100 1 x 20	3 x 72 2 x 72	15 15
Rivière-des-Mille-Iles A (km 35) B	200 120	2 x 100 1 x 100 1 x 20	3 x 72 2 x 72	12 12
Rivière du Nord (km 86)	80	1 x 100	1 x 72	15
Ottawa River (km 102)	725	11 x 100 1 x 20	10 x 72 2 x 36	27 12
South Nation (km 134)	80	1 x 100	1 x 72	8
Cobbs Lake Creek	35	1 x 40	1 x 36	8

Table F-10

Construction Cost Indices for Various Guideway Structures

Clearance	Length of Standards Beam					
	25 m		36 m		72 m	
0 m	100	71	164	117	-	-
5 m	140	100	194	139	-	-
10 m	164	117	228	163	-	-
15 m	204	146	228	173	-	-
20 m	-	-	256	183	-	-
25 m	-	-	296	211	296	211
30 m	-	-	-	-	320	229
40 m	-	-	-	-	390	279

Notes: 1. The indices on the left are based on a guideway at grade.
2. The indices on the right are based on a guideway with a 5 m clearance.

F.7 Stations

This section is a complement to Sub-Section 6.6.4. After a first sub-section describing the method used for estimating space requirements, four sub-sections describe each station in greater detail. The last sub-section describes cost and system aspects common to all stations.

F.7.1 Space Requirements

Space requirements for stations were estimated based on the assumption that sufficient capacity must be provided to handle peak loads in 2011, with an expectation of a median traffic: halfway between "minimum" and "maximum" forecasts described in Chapter 1 and Section 6.3.

Criteria for defining space requirements were derived from an analysis of typical VIA stations of medium size, such as that at Kingston. These criteria, used also for the Rail system, are the following: 1,67 m^2 per peak-hour boarding for passenger-related functions such as waiting area, food and beverage services, toilets, etc.; 1,25 m^2 per peak-hour boarding for operations-related functions such as: ticket counters, baggage and parcel handling facilities, and offices. The total space criterion, then, is 2,92 m^2 per peak-hour passenger to be served.

Table F-12, based on traffic data and forecasts presented in Chapter 1, gives the space requirements for the four stations and shows the intermediate steps in their derivation, which are the following:

- mean annual boarding (given in thousands of departures in Table F-13) is based on the mid-point between the minimum and maximum total traffic forecasts given in Table 1-15; this median is halved as boarding does not correspond to bi-directional trips, but to departures only;

- mean daily boarding (in departures per day) is equal to the mean annual boarding divided by 365;
- mean hourly boarding (in departures per hour) is equal to the mean daily boarding divided by 17,5 h/day,
- peak hourly boarding is equal to three times the mean hourly boarding;
- concourse design capacity (in departing passengers) is estimated based on a capacity equal to 50% of peak hour boarding: this presumes that the concourse population is turned over twice during the peak hour, which is consistent with the 30 min headways envisioned;
- concourse area (m^2) is equal to concourse design capacity (in departing passengers) times the space requirement criterion (in m^2/passenger).

F.7.2 Montreal Terminal

The Montreal Terminal will be located at Windsor Station. Platforms will be built adjacent to the existing concourse, over an area formerly occupied by low-level platforms used by intercity services; this area is presently not used, but it is still covered.

Renovation work will consist of removing the existing canopy, preparing the site, and remodeling the entrances to the concourse.

Three platforms will be built for the two Maglev guideways. All platforms will be built at car floor level, which is 0,6 m above the guideway suface and 10,9 m above top of rail. All platforms will be 175 m long and each will be equipped with two escalators to link it with the concourse level which will be enclosed below the platforms.

Lateral platforms will be 4 m wide, while the central platform is 6 m wide; this platform will be equipped, in addition to two escalators, with an elevator for use by handicapped passengers and for operational

Table F-11

Estimated Passenger Handling Capacity
(Maglev)

Station	Year	Mean Annual Boarding (1 000 trips)	Mean Daily Boarding (trips)	Mean Hourly Boarding (passengers)	Peak Hourly Boarding (passengers/h)	Concourse Design Capacity (pass.)	Area Requirement (m^2)
Montreal (1)	1991	519	1 420	80	240	120	
	1996	620	1 700	100	300	150	
	2001	744	2 040	120	360	180	
	2006	789	2 160	124	371	185	
	2011	793	2 175	125	375	190	555
West Island (2)	1991	298	815	50	150	75	
	1996	357	980	55	165	85	
	2001	430	1 180	67	200	100	
	2006	455	1 250	70	210	105	
	2011	458	1 255	72	215	110	321
Mirabel (3)	1991	238	650	37	112	55	
	1996	258	710	41	122	60	
	2001	281	770	44	132	65	
	2006	288	790	45	135	70	
	2011	288	790	45	135	70	204
Ottawa (4)	1991	663	1 815	105	315	160	
	1996	809	2 215	127	380	190	
	2001	992	2 720	155	465	235	
	2006	1 057	2 895	165	495	250	
	2011	1 061	2 905	166	500	250	730

Notes:
1. Based on Montreal - West Island traffic volumes in Table 1-15.
2. Based on the difference between Montreal - West Island and West Island - Mirabel traffic volumes in Table 1-15.
3. Based on Montreal-based airport-related traffic volumes in Table 1-11.
4. Based on Mirabel - Ottawa traffic volumes in Table 1-15.

functions. Ticket counters will be located in the enclosed and heated area under the platforms.

For weather protection, a canopy will cover the platforms. For security, a 1 m high wall will surround them; glass panels will bridge the gap between that wall and the canopy. As passengers do not stay there long, this protected space will not be heated.

Detailed renovation and construction costs are given in Table F-13.

F.7.3 West Island Station

This suburban station is the only one in the system to be an entirely new facility. Its construction will require the acquisition of a 7 000 m^2 land parcel to house:

- a 325 m^2 station building,
- a parking area for 250 cars;
- access and curb space;
- the platforms.

Land acquisition is likely to cause problems due to the proximity of two CN rights-of-way (Doney Spur and Montfort Subdivision), a complex highway network (Autoroute 13 and Boulevard Gouin), residential areas (including institutions on large landscaped properties and high-income housing), and a forest conservation area.

Lateral platforms will be used on account of short headways between departures and arrivals at peak hours; each will be 175 m long and 4 m wide. Each platform will be equipped with two escalators and an elevator. Due to the proximity of railway tracks crossed by the guideway, clearance between the underside of platforms and the terrain will be around 9 m. The top of platforms will be 10,9 above top of rail. Even if passengers do not stay long on platforms, they will be surrounded by a wall and windows for security and covered by a canopy for weather protection.

The station building will occupy an area of 325 m^2 as shown in Table F-13, for reasons explained in Sub-section F.7.1. To save on land requirements, the concourse will be built in part under the platforms.

The parking lot was dimensioned based on the mean daily boarding and the observed use of access modes from the West Island to Dorval Airport for domestic flights, as these flights (predomenantly to/from Toronto, hence lasting 1 hour) appear the most similar in character and duration to Montreal -Ottawa trips by Maglev.

Estimated costs for land acquisition and construction are given in Table F-13.

F.7.4 Mirabel Airport Station

When the Terminal 1 building for Mirabel Airport was designed, space was provisioned in the basement for a future Montreal - Mirabel transit system. This is where the Maglev station would be located; Mirabel is the only station along the route when there will be passenger movements into and out of the same trains: the station configuration must be designed accordingly.

Given short peak-period headways between successive opposite trains, as well as to reduce the risks associated with conflicting passenger movements on platforms, three platforms will be built. With such an arrangement, one platform can be used for boarding and the other for deboarding. All platforms will be 175 m long raised to car floor level, lateral platforms will be 4 m wide and the central one, 6 m wide.

Each platform will be linked to the concourse level above by two escalators. In addition, the central platform will be equipped with an elevator for use by handicapped passenger and for service requirements.

The estimated costs of building these facilities, including ticket counters and control areas on the concourse level, and making the necessary modifications to the terminal building are given in Table F-13.

F.7.5 Ottawa Terminal

Two guideway lanes will be built at grade in the space presently occupied by tracks at the Ottawa VIA station. As the Maglev service is expected to be the most extensive operation there, the guideways will be built nearest the station building.

Whereas only two platforms are needed to handle the expected traffic volume, three platforms will be built for increased operational flexibility and in preparation for a future extension of the service towards Toronto. Each platform, built at the level of the Maglev car floor, will be 175 m long and 4 m wide; actually, the guideway will be built so that the platform surface is at the same level as that of present day low-level train platforms. Whereas the inner platform will connect directly with the concourse, the two other platforms will be linked to it with a new tunnel. Stairs between that tunnel and these two platforms will be equipped with an incline wheel chair elevator. The tunnel will be connected to the concourse by an incline corridor.

It is presumed that the parking area and curb space of the existing station are adequate to handle the 2011 Maglev traffic loads. This is

Table F-22

Acquisition Requirements

STATION	WORK	UNIT COST	COST
Windsor	- Construction of 1 central platform 175 m x 6 m (\$/m^2)	200	210,000
	- Construction of 2 lateral platforms 175 m x 4 m (\$/m^2)	200	280,000
	- Install 6 escalators (ea.)	160,000	960,000
	- Install 1 elevator for handicapped (ea.)	160,000	160,000
	- Install 3 control counters	15,000	45,000
	- Demolish and construct a new roof over the platforms (global)	-	860,000
	- Finishing (global)	-	655,000
	TOTAL (including 5% contingency)		3,330,000
West Island	- Land acquisition 7,000 m^2	27	190,000
	- Construction of a 325 m^2 building	550	180,000
	- Construction of 2 lateral platforms 175 m x 4 m (\$/m^2)	200	280,000
	- Construction of a 250-place parking	-	90,000
	- Install 4 escalators (ea.)	160,000	640,000
	- Install 2 elevators for handicapped (ea.)	160,000	480,000
	- Finishing	-	150,000
	TOTAL (including 5% contingency)		1,940,000
Mirabel	- Create 3 openings in the concourse floor (global)	-	100,000
	- Install 6 escalators (ea.)	120,000	720,000
	- Install 1 elevator for handicapped (central platform) (ea.)	120,000	120,000
	- Construct 1 central platform 175 m x 6 m (\$/m^2)	100	110,000
	- Construct 2 lateral platforms 175 m x 4 m (\$/m^2)	100	140,000
	- Finishing (global)	-	15,000
	TOTAL (including 5% contingency)		1,410,000
Ottawa	- Construct 1 central platform 150 m x 6 m (\$/m^2)	100	90,000
	- Construct 2 lateral platforms 150 m x 4 m (\$/m^2)	100	120,000
	- Structural work (global)	-	90,000
	- Construct 1 tunnel (global)	-	35,000
	- Install 2 incline plane elevators for wheel chairs	37,500	75,000
	- Install 2 control counters	15,000	30,000
	- Finishing (global)	-	70,000
	TOTAL (including 5% contingency)		540,000

plausible as the frequency will be increased considerably vis-a-vis present day operations: space required in the station will not increase in direct proportion to traffic volume.

F.7.6 Other Station Costs

The cost of building guideways through stations are included in the infrastructure costs. For cost estimation purposes, elevated platforms are considered as a free-standing separate structure whereas, in reality, they would be integrated into the guideways structure.

The cost of computer terminals and associated hardware for reservations and ticket transactions are estimtatestimated as part of the station operating costs.

The concourse level area required at Windsor Station and Ottawa Terminal are considered to be leased from Canadian Pacific and VIA Rail respectively. The annual rental charges were estimated for Class A buildings in the downtown area, these rates are currently $183/m^2$ in Montreal and $215/m^2$ in Ottawa. These rentals do not include various other charges such as: maintenance, electricity, security, taxes, etc. Such costs are considered elsewhere as part of station operating costs and building maintenance costs.

As to Mirabel Airport Station, it is presumed that space and services are made available free of charge by Transport Canada.